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TESTS OF FLUIDIZED BED BURNERS FOR THE LINS METHOD OF OIL RECOVERY

SANTA CRUZ, CALIFORNIA

TESTS OF FLUIDIZED BED BURNERS FOR THE LINS METHOD OF OIL RECOVERY

by

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Santa Cruz Thermal Recovery Experiment

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SUMMARY

A series of tests has been completed in which LINS fluidized bed burners were used to heat intervals of from 50 to 100 feet in thickness. Design and operating data were obtained and several functions, with which burners can be compared, have been correlated with these data. It has also been shown that the gas produced by the LINS process is a suitable fuel for these burners.

INTRODUCTION

Since 1955, a series of tests has been performed by Husky Oil Company and Svenska Skifferolje Aktiebolaget, near Santa Cruz, California, with the purpose of adapting the Ljungstrom In-Situ (LINS) method to the recovery of oil from tar sand. In October, 1957, these companies were joined by Union Oil Company of California and since that time, oil and gas recoveries, burner design, and materials of construction have been studied. Results concerning oil and gas recoveries and earlier burner tests have been reported previously[1,2].

The burners tested before October, 1957, included a number of different designs and sizes, however the so-called "sand burners", in which heat is transferred to the formation by a fluidized sand bed, has proven to be by far the most efficient burner. This burner has also been used in a 100-well field test[2]. Because of the success of this burner and the fact that the earlier tests were concerned with heating short intervals, usually less than 50 feet, this series of tests was undertaken to develop burner design and operating data for intervals as large as 100 feet.

DESCRIPTION OF TEST FACILITIES

Burners and Wells

The tests were conducted in three wells, numbered 120, 122, and 124, which were drilled and completed as follows:

	Well 120	Well 122	Well 124
Outer Casing Depth	100'	135'	160'
Burner Casing Depth	95'	130'	160'
Nominal Burner Casing Diameter	3"	$3\frac{1}{2}$"	4"

The wells were drilled with a $12\frac{1}{4}$-inch bit and the outer casing was $10\frac{3}{4}$-inch Armco "Spiralweld" pipe. The outer casing was present to exclude formation water which would disturb the temperature measurements. Burner casings were schedule 40, carbon steel pipe. As shown on Figure 1, the burner casing was centered in the outer casing, and a 2-inch pipe was strapped and spot-welded alongside the burner casing to serve as a thermocouple well. The annulus between the burner casing and outer casing was then filled with sand to prevent convection and to provide heat capacity.

The burners were of the same general design as the sandburners used in previous tests. The supply pipes were $\frac{1}{2}$-inch, schedule 40, carbon steel pipe, except for the last 20 feet, which was $\frac{1}{4}$-inch, schedule 80, 18-8 stainless steel pipe. The cones were cast 25-12 stainless steel with an inside diameter increasing from 0.30 to 1.32 inches. The burner tubes were 1, $1\frac{1}{4}$, and $1\frac{1}{2}$-inch, schedule 40 pipe of varying lengths as shown on Tables 1 through 3. Five to ten feet of the burner tube, nearest the cone, was 18-8 stainless and the remainder was carbon steel.

The sand used in these tests was a commercial grade of quartz sand, designated Halliburton 10-30 Hydrafrac sand, which was nominally 10 to 30 mesh, spherical sand. The average particle diameter of the new sand was 0.0316 inches. Sieve analyses of new and used sands are shown on Figures 2 and 3, and Tables 9 and 10. Average particle diameters varied from 0.0167 in. to 0.0255 in. after the sand had been used in the tests; however, most of this wear occurred during a "break-in" before the tests.

Fuel Gas Supply

In most of the tests the fuel was propane, although five tests were run with sweetened produced gas from the 100-well test. Figure 4 is a flow sheet of the gas supply and metering equipment. The system pressure was controlled by regulating the pressure in the line from the propane tank.

A bleed from this line, to a balance valve, was used to maintain the same pressure in the air line as in the propane line. Each stream was then regulated and metered separately before they were mixed. Usually three tests were in progress at once and each test was controlled by a pair of rotameters and needle valves. The pressure in the propane storage tank was maintained at 80 psig by heating the tank with infra-red lamps, which were controlled by a pressure switch.

The hydrogen sulfide was removed from the produced gas in an iron-sponge sweetener. This gas was then compressed and regulated at a pressure to match that in the air supply line. The produced gas was metered and regulated, in the same way as the propane, with a rotameter and a needle valve. The composition of this gas is shown on Table 11.

Temperature Measuring Equipment

Casing temperatures were measured in the 2-inch thermocouple well shown on Figure 1. The iron-constantan thermocouples were mounted on a $\frac{1}{2}$-inch pipe with the thermocouple junctions attached to the centralizers. The $\frac{1}{2}$-inch pipe could be moved up or down to change the depth of the thermocouples. A common iron wire was used as one side of all the thermocouples with a separate constantan wire to each couple. The iron side was grounded, and all the casings were grounded together to eliminate any current flow caused by differences in ground potential. The thermocouple potentials were recorded on a Leeds & Northrup, "Speedomax", 12-point recorder. When the thermocouple positions were changed, it usually took less than an hour for them to reach a constant temperature.

DESCRIPTION OF TESTS

Original Test Program

After a few tests had been run, the original test program had to be revised. This was because of the increase in bed expansion above the previously predicted values. In addition several supplementary tests were made, based on the results of the tests in the revised program. The development of these test programs and the operation of the tests are described below.

These tests were intended to investigate the use of sandburners in intervals of 50 to 100 feet in thickness, and to obtain design data. The following factors were of interest in burner design:

1. Fuel Gas
2. Heat Input
3. Burner Casing Diameter
4. Burner Tube Diameter
5. Burner Tube Length
6. Type of Sand
7. Size of Sand Particles
8. Amount of Sand
9. Materials of Construction.

Several of these factors were eliminated from consideration in these tests. The size and type of sand were not varied because of the limited types of sand available and because previous tests had shown that sands in the range of 10 to 30 mesh were satisfactory. A spherical quartz sand was used because of its resistance to wear. This is important in maintaining the same particle size and shape over a series of tests.

Materials of construction could not be studied in these tests because of the short duration of each test. Casing materials were being tested in a concurrent seven-well test, however.

The only fuel gas available in suitable quantities was propane. Therefore it was necessary to use propane in most of the tests. However, a limited quantity of production gas was available from the 100-well field test, and this was used in a few burner tests. Production gas, natural gas, or mixtures of these would probably be used in a commercial operation.

Two important factors which depend on the fuel gas are the exhaust gas flow rate, compared to the heat input, and the flame velocity. For propane, natural gas, and production gas, the amount of exhaust gas per 1000 Btu is 10.3, 10.6, and 10.0 Scf, respectively. Thus, these fuels are practically equivalent on this basis. Burning velocities for hydrogen, methane and propane are shown on Figure 5 at various fuel-air ratios. Methane and propane flame velocities are almost equal, thus one would expect

them to behave similarly in a LINS burner. The produced gas consists of about 40% hydrogen, 30% methane, and about 30% heavier hydrocarbons (see Table 11). Thus its flame velocity would probably lie somewhere between those of methane and hydrogen, higher than either methane or propane. Although temperature, tube diameter, and pressure effect the flame velocity, the above relationships between the flame velocities of these fuels should not change radically for any particular burner. Therefore it was felt that propane could be used instead of natural gas and that a few tests should be made using production gas, depending upon its availability.

Thus, the following variables were to be studied in these tests:

1. Heat Input
2. Burner Casing Diameter
3. Burner Tube Diameter
4. Burner Tube Length
5. Amount of Sand.

Because of the lack of knowledge of interactions among variables, it was felt that the most efficient experimental design would be a complete factorial design.[3,4,5,6] This requires that each variable be studied at two levels, which means that with n variables there would be 2^n experiments. In this case 32 experiments would be required. It would be difficult to cover a range of burner dimensions and operating conditions while maintaining each of the above variables at two levels. A burner tube of a given diameter can be used with a limited range of flow rates because of the danger of flashback of the flame at low rates and flame blow-out at high rates. Likewise, the flow rates which provide good fluidization of the sand bed lie in a certain range, and a given annulus area can be used only for a particular range of flow rates. Thus burner tube diameter and burner casing diameter are not completely independent variables, but they are related by the above considerations. Therefore, the burner variables were redefined as:

1. Mass flow rate, G (lb/sec-sq.ft. of annulus area).

2. Sand height in the annulus divided by the burner tubing length, L_S/L_B.

3. Burner tubing length divided by the area of the annulus, L_B/A_A (ft./sq. in.).

4. Burner casing diameter, D_c (inches).

If the choice of casing diameter also determines the burner tube diameter, as was assumed, then the four variables given above would define the dimensions and heat input for a burner. Therefore a series of 24 tests

was programmed as shown on Table 1. Because of the economic importance of casing diameter, three sizes of casing were used instead of two.

Preliminary Tests

Fluidization Tests with Air

Pressure drop data were taken in each well before the burners were tested. These data were taken with varying air flow rates at several sand levels. The data, which are shown on Table 8 and Figures 6 to 8, were used to help estimate the pressure drops to be encountered in the burner tests, as well as to check the feasibility of the operating conditions specified in the test program.

Preliminary Burner Tests

The first burner tests were run in well 120. The burner was operated for about 4 days to heat the casing to a temperature where water condensation would not be a problem, and to test the equipment. The test program shown on Table 1 was started on August 18, 1958. Table 5 shows the results of the first three tests, two of which (1 and 3) were repeated.

After the first three tests had been completed, it became apparent that the slugging and transport of sand out of the bed was becoming more pronounced. Samples, taken after each test, showed rapid wear of the sand. Unfortunately, the containers for all the samples, except the one taken before test No. 2 (at 367 hours), were broken and a sieve analysis was made only on this sample, and on one taken later at about 800 hours (see Table 9 and Figure 2). Table 5 shows that the ratio of the height of the slugging zone to the settled sand level, L_{HS}/L_S, increased from 3.2 in Test 1 to 3.5 in Test 1A, and from 3.8 in Test 3 to 4.8 in Test 3A. It was apparent from these results that many of the tests in the original test program of Table 1 could not be run because the increased bed expansion would cause excessive sand losses.

Revised Test Program

A revised test program was set up in which the mass flow rates were set at 0.233 and 0.291 lb/ft^2 sec, and the sand level to tubing length ratios at 0.400 and 0.500. Other variables remained as originally fixed. These tests were designed to allow minimum bed expansions of 2.5 and maximum height of slugs, compared to settled bed height, of 4.0. It was necessary that the fluidized bed be high enough to cover the burner cone at all times, to avoid overheating the cone. The top of the slugging zone, however, could not reach the top of the casing or excessive sand losses would result. This would, of course, make it difficult to control the amount of sand in the casing. The revised test program is shown on Table 2.

Tests in Well 120

Well 120 had a 3-inch burner casing, 95 feet long. All of the tests shown on Table 2 for this well were completed. These results are shown on Table 6 and Figures 9 to 27. In some cases, more than one temperature curve was used in a given test and these curves, along with the corresponding data, are denoted by the letter a, b, c, etc., e.g., tests 120-2a and 120-2b. The operating conditions for these tests are shown on Table 4.

After the tests with propane had been completed, four of the tests (121 series) were repeated using produced gas from the 100-well test. The composition of this gas, before and after hydrogen-sulfide removal, is shown on Table 11. This fuel gas was much easier to light than propane, probably because of its higher flame velocity.

At this time, inasmuch as many tests remained to be completed in the other wells, it was felt that well 120 could be used to run some tests with 1-inch burner tubing. No data had been taken previously to determine the maximum capacity of this smaller burner. A 1-inch burner was set in well 120 and, without sand in the casing, the heat input was increased in an attempt to exceed the capacity of the burner. At 60,000 Btu/hr, the capacity of the available metering equipment was exceeded, and the test was discontinued.

Several additional burner tests were made with one-inch burners in well 120. These tests which are denoted by the letter "B" are listed in Table 3. Insufficient temperature data were taken during tests 120-5B through 120-7B because of their short durations. One additional test, 120-9B, was made at the same conditions as 120-8B but with a helical baffle located 25 feet from the surface on the supply pipe. Test 121-4B could not be run because of the high sand losses. Because 121-5B was to have the same amount of sand with a higher heat input, it was not attempted, and 121-6B was run instead with a lower heat input of 50,000 Btu/hr. This test was run satisfactorily. One additional test was run with the one-inch burner using produced gas from the 100-well test. This test, 121-3BS, was run at about the same heat input and sand level as test 121-1B(see Table 4).

After the final test was made in well 120, a sample of the burner sand was taken and analyzed. The sieve analysis is shown on Table 9 and Figure 2. It is apparent that most of the sand wear occurred during the first 800 hours and that an equilibrium average particle size, of about 0.022 inches, was maintained during most of the tests.

Tests in Well 122

Well 122 contained 130 feet of $3\frac{1}{2}$-inch casing. The original test program for this well, tests 9 to 16 in Table 1, was changed to that shown on Table 2, at the same time that the tests for well 120 were revised. The

results of the tests are shown on Table 6 and Figures 28 to 34. The first four of these tests, 122-1 to 122-4, were completed without trouble. The thermocouples shorted several times during this test, apparently because of carbonization of oil and grease in the thermocouple insulation. The thermocouple tubing apparently had not been cleaned sufficiently. Before the test could be completed, the burner cone failed. Although there was no apparent casing damage, the thermocouples were destroyed and, in subsequent tests, the temperatures were taken with a single thermocouple on a cable or with a thermometer in a temperature bomb. This bomb was constructed of pipe and had a high enough heat capacity to allow the thermometer to be raised to the surface and read before any measurable temperature drop occurred. Test 123-1 was never completed. Test 123-2 was run next. There was considerable difficulty in maintaining the correct sand level but, after about 10 days, the sand level became relatively stable and the test could be completed. The difficulty was apparently caused by sand sticking to the sides of the casing where water had condensed, as well as sand being carried out of the casing.

During test 123-3, the burner casing failed. This failure may have been the result of damage to the casing when the cone failed during test 123-1. The top of the fluidized bed was relatively close to the burner cone in these tests; therefore, tests 123-3 and 123-4 were not run. Instead of risking equipment damage on these tests it was decided to run some tests with shorter burner tubes. In view of the success with 1-inch burner tubes in well 120, at this time, one-inch burners were used and tests 122-1 to 122-4 were to be duplicated. These proposed tests, shown on Table 3, were called 122-1B to 122-4B. Test 122-1B was completed, however test 122-2B had very high sand losses, in the range of 100 inches per day. This test was to be run at the same flow rate as 122-2, but with a higher sand level, closer to the conditions of 122-4. However, unlike 122-4, this test, as well as 122-4B, could not be completed, because of high sand losses. Test 122-3B, at the lower flow rate, was completed without excessive sand losses.

Tests in Well 124

As in wells 120 and 122, the original test program for well 124 (Table 1) was revised and is shown on Table 2. Test 124-1 could not be run with 27.3 feet of sand because the cone was too close to the top of the fluidized bed to prevent overheating. Therefore, this test was completed with 38.7 feet of sand. The remaining tests in this series, if they could be run, would probably have located the burner cone at a very high position in the fluidized bed. This would increase the danger of overheating the cone and casing. Therefore a new series of tests, 126-1 to 126-4, was planned with shorter, 53-foot, burner tubes. This test program is shown on Table 3. These tests were all run successfully. The results are shown on Table 6 and the temperature curves on Figures 35 to 41.

After the programed tests had been completed in well 124, one additional test, 127-1, was run with the same conditions as 126-1, except with a 30-foot burner tube instead of a 53-foot tube. This temperature curve, Figure 40, showed an abrupt drop in temperature in the lower 30 feet of the casing. It was later discovered that the bottom of the burner had been 30 feet above the bottom of the casing. This test was then repeated, as test 127-2, with the burner at the bottom of the casing.

Errors in the Data

The temperatures shown on Figures 9 to 41 appear to vary erratically at certain points along the casing. These variations appear at approximately the same depth for all the curves in any given well. The source of heat is the burner cone, with the burner tube and hot gas at the bottom of the burner supplying lesser amounts of heat. Therefore it is impossible to have a point above the cone which is at a higher temperature than another point located closer to the cone. This is also true along the burner tube, except at the bottom where the hot exhaust gas entering the annulus can cause a temperature peak. These apparent variations were probably caused by the variation in the degree of contact between the centralizers, where the thermocouples are located, and the thermocouple tubing. Another reason may be deposits of sand which were occasionally observed on the inside surface of the burner casing. These sand deposits consisted of fine clay and silt particles which were held on the casing wall by moisture. In one case one of these ring-shaped deposits became fired and a very hard, brick-like material resulted. Variations in temperature caused by the accuracy limitations of the thermocouples and the recorder were small by comparison, being in the range of 25°F or less. According to the above assumptions, any large errors in temperature would result in low readings, and it is not likely that a temperature reading would be higher than the actual temperature in the casing. For this reason, the curves were drawn through the maximum temperatures, except at depths where a minimum point could actually exist.

Pressure drop data were obtained by recording the pressures in the fuel gas at the point where it entered the hose leading to the supply pipe. Pressure drops in the supply pipes had previously been recorded, and these pressure losses were deducted to give the pressure drop through the sand bed. These pressure losses are probably in error in some cases because no record was made of the individual lengths of $\frac{1}{4}$-inch and $\frac{1}{2}$-inch pipe in the supply pipe. Most of the supply pipe pressure drop should have occurred in the $\frac{1}{4}$-inch portion of the supply pipe. Some of these data could be in error by as much as 20% for this reason. Any other errors in pressure measurement would be quite small by comparison.

The fuel gas and the air flow rates were both measured with rotameters before they were mixed. These rotameters were read and

adjustments in flow rates were made hourly during the tests. Because of the slugging in the sand bed, the rotameter floats and pressure gauges had a tendency to oscillate around a mean value. In addition, there were times when the propane condensed in the meters and lines. All temperature curves and data were obtained during periods of stable operation, and in the event of any unusual occurrence which might effect the results, the test was continued until a period of stable operation was again reached. Usually about 12 hours was required to record the data for a temperature curve and the average heat input over this period was calculated by averaging the flow rates calculated from each hourly reading. Thus the average gross heat inputs were probably not in error by more than a few percent.

The sand level was measured daily by shutting the burner off and pulling it up until it was out of the sand bed. The sand level was then measured by the length of casing it occupied while settled and then was converted to the height this amount of sand would occupy in the annulus. Sand was generally lost when it became ground into small enough particles to be carried out with the exhaust gas. Occasionally a slug reached the surface of the casing and larger sand particles were lost, but this was quite rare in these tests. During the early periods of operation of some tests, when parts of the casing were below the dew point, water condensing on the casing walls would cause sand to stick to the wall. This sand would be considered lost during a check of the sand level and would be replaced. Later, when the casing was heated to a higher temperature, this sand would fall back into the bed. These variations in sand level were occasionally as high as two feet per day, although in most tests the sand level became fairly constant during the later periods when temperature data were being taken. The sand level measurement itself could be in error by as much as $\frac{1}{2}$ foot, depending upon the degree of care used by the project personnel making the measurement. Temperature data were not taken if the sand level varied to a degree considered excessive for that test, which was usually about 5% of the total sand level.

RESULTS

Definition of Variables

Because the objective of these tests was to develop information and data which will be useful in designing and evaluating burners, it was necessary to define quantities by which burners could be compared. A well designed burner should: (1) heat the required interval of formation; (2) supply heat uniformly over the interval; (3) supply heat at a given rate to the interval; (4) make efficient use of the fuel; and (5) operate with a low pressure drop.

The variables used to describe the above quantities are:

(1) Length of heated interval, L_B. This has been defined as the distance between the two points, on the temperature curve, where the temperature rise is one-half the maximum temperature rise. The height of the fluidized bed, L_B', is measured from the bottom of the burner tube to the top of the heated interval. Usually these two lengths coincide. These definitions are arbitrary and there are others which could be used.

(2) The ratio of the average temperature rise in the heated interval to the maximum temperature rise, E. This is a significant quantity because the average temperature rise is proportional to the average heat input, and the maximum temperature rise is limited by the maximum allowable temperature of the burner casing. An ideal burner is one where this ratio is unity. The average temperature was found by graphically integrating over the heated interval on the temperature curve.

(3) The actual heat input, through the casing, in the heated interval, H_A. This is the heat input which must be maintained in order to heat a formation to a given temperature, in a given time, with a given well spacing. Assuming that casing temperature is proportional to heat input along the entire casing, the fraction of the heat delivered to the heated interval can be found by integrating along the temperature curve. This fraction is then multiplied by the gross heat input less the sensible heat of the exhaust gases.

$$H_A = (H - GA_A C_e T_E) \frac{\int_{L_H} (T - T_o)\, d\,L}{\int_{\text{casing}} (T-T_o)\, d\,L}$$

The quantity, $H - GA_A C_e T_E'$, is shown on Figure 42 for propane and production gas.

(4) The ratio of the actual heat input to the formation compared to the gross heat input to the burner, H_R.

(5) The pressure drop in the fluidized bed per foot of settled bed, $\Delta P/L_S$. This pressure drop could be compared to the length of fluidized bed or heated interval also. These lengths must be calculated and are not known as accurately as the height of the settled bed, therefore they were not used.

(6) Bed expansion, L_B'/L_S. In some tests, the thickness of the heated interval was less than the height of the fluidized bed, because of poor heat transfer to the lower part of the casing. Therefore the bed expansion was also studied.

Methods of Data Analysis

The test program, which was set up as a complete factorial design, was changed extensively as the tests progressed. Also, the data were not taken at discrete levels of each variable. Therefore it was not possible to use the factorial design analysis to examine the effects of each variable, or the possible interactions among variables. The data were correlated using a linear regression analysis computer routine (Union Oil Co. Routine No. 0054). This routine fits a linear equation of the type shown below by the method of least squares[1, 3]:

$$y = a_o + a_1x_1 + a_2x_2 + a_3x_3 + \dots + a_nx_n$$

where y is the dependent variable, x_1 to x_n are the n independent variables, and a_o to a_n are constant coefficients. In addition, the routine supplies the necessary data to calculate the standard deviation about the above equation, and the standard deviation of each coefficient, a_i. Each coefficient, a_i, was tested by the "t" test, at the 95% level, to determine if it was significantly different from zero. If not, it was eliminated in further trials with the regression routine, except in a few cases where there was reason to believe that there might be interactions between two variables. In this case the elimination of one sometimes made the other become significant.

When the original test program was designed, the following independent variables were considered:

1. mass flow rate, G..
2. sand height divided by burner tube length, L_S/L_B.
3. burner tube length divided by area of annulus, L_B/A_A.
4. burner casing diameter, D_c.

These four variables would describe a burner if the diameter of the burner tube were set by the casing diameter, i.e., if there were only one burner diameter which could be used with a given casing diameter. It was assumed that this was true because of the limitations imposed by the flame velocity and the flow rates necessary for fluidization. This assumption was proved invalid when two different burner diameters were used successfully in wells 120 and 122. Therefore an additional quantity is necessary to describe the burner. This could be burner tube diameter, burner tube length, or annulus area. The burner tube length was used because it was felt that it might be correlated more easily with some of the dependent variables, i.e., length of heated interval, L_H, and the heat input ratio, H_R. One additional factor was introduced when some tests were made with production gas as fuel. This qualitative factor was called the fuel number, F, and was zero when the fuel was propane and equal to one when the fuel was produced gas from the 100-well test. When produced gas is being considered, this is equivalent to changing the coefficient a_o in the above linear equation to $a'_o = a_o + a_F$, where a_F is the coefficient of F.

Heated Interval and Bed Expansion

The heated interval is defined as the distance, along the burner casing, between the two points where the temperature rise is equal to one-half the maximum temperature rise. Usually, but not always, the lower of these points was within a few feet of the bottom of the burner tube. The height of the fluidized bed is defined as the distance from the bottom of the burner tube to the top of the heated interval. In most cases these two lengths coincide. The bed expansion is the ratio of the height of the fluidized bed to the height of the unexpanded bed.

Table 12 shows the results of applying the regression analysis to the heated interval data. In the first trial, an attempt was made to correlate heater interval, L_H, with all of the six independent variables plus the term $D_c \sqrt{G}$. The latter term was used because of the frequency with which it appears in fluidized bed heat transfer correlations, however it was of no significance in any of the correlations in these tests. The significance of each factor was tested by applying the "t" test to determine if the coefficient was significantly different from zero. This means that the coefficient is not significant if t is less than 2.01, at the 95% level of significance with 50 degrees of freedom. Thus the fuel, casing diameter and the term, $D_c \sqrt{G}$, had no significant effect on the length of the heated interval. The equation which resulted from the regression analyses is:

$$L_H = 8.10 + 141\ G + 0.755\ L_B + 44.8\ L_S/L_B - 4.03\ L_B/A_A$$

The range of L_H was from 54-1/2 to 101 feet with mean value of 72.68 feet and a standard deviation from the regression equation of ± 5.27 feet.

Inasmuch as the height of the fluidized bed did not always coincide with the heated interval, the bed height was correlated separately, as the bed expansion, L_H'/L_S. Table 15 shows the results of these correlations. The fuel and burner tube length, as well as the term $D_c \sqrt{G}$ were found to be insignificant. Thus the following equation resulted:

$$L_H'/L_S = 7.93 - 4.68\ L_S/L_B - 0.315\ L_B/A_A + 7.31\ G - 0.568\ D$$

The bed expansion varied from 2.46 to 5.35, with a mean of 3.41 and a standard deviation from the regression equation of 0.275.

Temperature Ratio

The results on Table 14 show that the only significant factors affecting the temperature ratio are the fuel and the ratio of burner tube length to the area of the annulus. It is interesting to note that, on the average, the use of produced gas instead of propane lowers the temperature ratio by 4.81%. The equation for the temperature ratio is:

$$E = 89.8 - 1.44\ L_B/A_A - 4.81\ F$$

The mean value of E is 79.01% and the range is from 65.0 to 88.6% with a standard deviation about the regression equation of 4.79%.

Actual Heat Input

The actual heat input to the formation was correlated as shown on Table 13. The effects of fuel, burner length divided by annulus area, and the term, $D_c \sqrt{G}$, were all insignificant. The equation which resulted is:

$$H_A = -61.8 + 213\ D_c - 3.49\ L_B + 1222\ G - 394\ L_S/L_B$$

This heat input varied from 460 to 802 BTU/ft-hr. The mean value was 619.9 BTU/ft-hr and the standard deviation for the above equation was ± 34.6 BTU/ft-hr.

Heat Input Ratio

The heat input ratio is correlated in Table 16. This term, which is the ratio of the heat supplied to the formation in the heated interval compared to the gross heat input, could also be called the burner efficiency. The only significant factors affecting this ratio

were casing diameter and mass flow rate. The equation was:

$$H_R = 0.952 - 0.0796\ D_c + 0.342\ G$$

Thus smaller casings and higher flow rates provide more efficient burners. The heat input ratio varied from 0.626 to 0.833 with a mean value of 0.767. The standard deviation of the above equation was ± 0.034.

Pressure Drop

An attempt was made to correlate the pressure drop per foot of settled sand bed with the particle Reynolds number, N_{Rep}, and the hydraulic radius, r_h. These results are shown on Table 17. Figures 6 to 8 show that the flow rate has no significant effect on the pressure drop if the flow rate is high enough to maintain a fluidized bed. The fact that the particle Reynolds number has no effect on the pressure drop shows that the particle size does not affect pressure drop, within the narrow range of particle size used. The equation for the pressure drop is:

$$\Delta P/L_S = 2.73 - 3.55\ r_h$$

The pressure drop varied from 0.506 to 1.60 psi/ft with a mean of 1.136 psi/ft. The standard deviation of the above equation is 0.130 psi/ft.

Burner Capacity

No data were taken to determine the capacities of the burner tubes. The maximum heat inputs used in the tests were 66,500 BTU/hr with a 1-inch burner, 74,600 BTU/hr with a 1-1/4 inch burner, and 95,600 BTU/hr with a 1-1/2 inch burner.

Sand Losses

Sand loss data were taken and are shown on Table 4. These data are erratic and show no particular trend. Apparently the sand losses caused by attrition were very small, compared to the losses caused by slugs coming out the top of the casing. If there was moisture on the casing wall, sand could collect and stick to the casing and then be considered as lost. Later when the casing became dry this sand would fall back into the bed and be considered as a gain in sand level. In addition, the accuracy of the sand level measurement was about 1/2 foot, and being a difficult quantity to measure, a given sand level would be measured differently by different individuals.

Range of Data

The range of each of the independent and dependent variables is listed on Table 18. Because of the errors involved when non-linear functions are approximated by linear equations, one should be extremely cautious in using these equations outside the range of the original data. Probably the ranges of most of these variables include the most practical and economical operating points.

CONCLUSIONS

There are few definite conclusions which can be drawn from these tests, inasmuch as the main objective was to obtain burner design and operating data. Therefore the most important results are in the form of equations which resulted from the correlation of these data.

It was shown however that:

1. Gas fired LINS burners can be used to heat formations as thick as 100 feet, and indications are that, with larger burners, even larger intervals could be heated.

2. The gas, which is produced by the LINS process, is a suitable burner fuel and in some respects is easier to use than propane.

3. Quartz sand, as was used in these tests, showed very little wear after an equilibrium particle size distribution had been reached. This occurs after a few hundred hours of operation.

4. The heat input capacities of the various sizes of burner tubes have not been determined, and this should be done.

5. If there are two different burner designs which will heat the same interval, generally the one with the smaller casing and higher flow rate will be the more efficient design.

These tests were operated by a team consisting of W. J. Shirley, J. H. Duir, and the authors.

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LIST OF SYMBOLS

A_A - Cross-sectional area of annulus between burner casing and burner tube (in^2).

C_e - Heat capacity of exhaust gas (BTU/scf °F).

D_B - Outside diameter of burner tube (in.).

D_c - Inside diameter of burner casing (in.).

E - Ratio of average casing temperature rise to maximum temperature rise (%).

F - Fuel number (0 for propane, 1 for produced gas).

G - Mass flow rate (lb/ft^2sec).

H - Gross heat input to burner (BTU/hr).

H_A - Actual heat input to formation within heated interval (BTU/ft-hr).

H_R - Ratio of heat delivered to the formation within the heated interval to the gross heat input to the burner ($H_R = H_A L_B / H$).

L - Distance along the burner casing (feet).

L_B - Length of the burner tube (feet).

L_H - Length of the heated interval of formation, measured between the two points where the temperature increase is 50% of the maximum (feet).

L_{HS} - Height of the slugging bed (feet).

L_S - Height of the settled sand bed in the annulus between the burner tube and the burner casing (feet).

L_H' - Height of the fluidized bed, measured from the bottom of the burner casing to the top of the heated interval.

P - Pressure of the fuel gas at the surface. (psig)

ΔP - Pressure drop in the sand bed (psi).

ΔP_o - Pressure drop in the supply pipe and burner tube (psi).

List of Symbols (continued)

r_h - Hydraulic radius of annulus (in.).

T - Temperature along burner casing (°F).

T_o - Ambient temperature (°F).

T_E - Temperature of exhaust gas (°F).

Tmax - Maximum temperature along burner casing (°F).

Tavg - Average temperature in the heated interval (°F).

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Table 1

ORIGINAL TEST PROGRAM

Test No.	Burner Casing Diam.	Burner Casing Length	Burner Tubing Diam.	Burner Tubing Length	Mass Flow Rate (lb/ft^2sec)	Sand Level / Tbg. Length	Tbg. Length / Annulus Area (ft/in^2)	Heat Input To Burner (BTU/b-hr)	Sand Level (ft)
1	3"	95"	1-1/4"	36'	0.269	0.511	6.92	46,000	18.4
2	"	"	"	"	"	0.650	"	"	23.4
3	"	"	"	"	0.342	0.511	"	58,600	18.4
4	"	"	"	"	"	0.650	"	"	23.4
5	"	"	"	46'	0.269	0.511	8.83	46,000	23.5
6	"	"	"	"	"	0.650	"	"	29.9
7	"	"	"	"	0.342	0.511	"	58,600	23.5
8	"	"	"	"	"	0.650	"	"	29.9
9	3-1/2"	130'	"	53.3'	0.269	0.511	6.92	68,000	27.2
10	"	"	"	"	"	0.650	"	"	34.6
11	"	"	"	"	0.342	0.511	"	86,800	27.2
12	"	"	"	"	"	0.650	"	"	34.6
13	"	"	"	68.1'	0.269	0.511	8.83	68,000	34.8
14	"	"	"	"	"	0.650	"	"	44.2
15	"	"	"	"	0.342	0.511	"	86,800	34.8
16	"	"	"	"	"	0.650	"	"	44.2
17	4"	160'	1-1/2"	68.3'	0.269	0.511	6.92	86,800	34.9
18	"	"	"	"	"	0.650	"	"	44.4
19	"	"	"	"	0.342	0.511	"	110,900	34.9
20	"	"	"	"	"	0.650	"	"	44.4
21	"	"	"	87'	0.269	0.511	8.83	86,800	44.5
22	"	"	"	"	"	0.650	"	"	56.5
23	"	"	"	"	0.342	0.511	"	110,900	44.5
24	"	"	"	"	"	0.650	"	"	56.5

Table 2

REVISED TEST PROGRAM

Test No.	Burner Casing Diam.	Burner Casing Length	Burner Tubing Diam.	Burner Tubing Length	Flow Rate ($lb/ft^2 sec$)	Sand Level / Tbg.Length	Tbg.Length / Annulus Area (ft/in^2)	Heat Input (BTU/hr)	Sa[illegible] Level
120-1	3"	95'	$1\frac{1}{4}$"	36'	0.233	0.4	6.92	40,000	14.
120-2	"	"	"	"	0.291	"	"	50,000	"
120-3	"	"	"	"	0.233	0.5	"	40,000	18.
120-4	"	"	"	"	0.291	"	"	50,000	"
121-1	"	"	"	46'	0.233	0.4	8.83	40,000	18.
121-2	"	"	"	"	0.291	"	"	50,000	"
121-3	"	"	"	"	0.233	0.5	"	40,000	23.
121-4	"	"	"	"	0.291	"	"	50,000	"
122-1	$3\frac{1}{2}$"	130'	"	53.3'	0.233	0.4	6.92	58,500	21.
122-2	"	"	"	"	0.291	"	"	74,000	"
122-3	"	"	"	"	0.233	0.5	"	58,500	26.
122-4	"	"	"	"	0.291	"	"	74,000	"
231-1	"	"	"	68.1'	0.233	0.4	8.83	58,500	27.
123-2	"	"	"	"	0.291	"	"	74.000	"
123-3	"	"	"	"	0.233	0.5	"	58,500	34.
123-4	"	"	"	"	0.291	"	"	74,000	"
124-1	4"	160'	$1\frac{1}{2}$"	68.3'	0.233	0.4	6.92	75,800	27.
124-2	"	"	"	"	0.291	"	"	94.700	"
124-3	"	"	"	"	0.233	0.5	"	75,800	34.
124-4	"	"	"	"	0.291	"	"	94,700	"
125-1	"	"	"	87'	0.233	0.4	8.83	75,800	34.
125-2	"	"	"	"	0.291	"	"	94,700	"
125-3	"	"	"	"	0.233	0.5	"	75,800	43.
125-4	"	"	"	"	0.291	"	"	94,700	"

Table 3

SUPPLEMENTARY TEST PROGRAM

Test No.	Burner Casing Diam.	Burner Casing Length	Burner Tubing Diam.	Burner Tubing Length	Flow Rate ($lb/ft^2 sec$)	Sand Level / Tbg. Length	Tbg. Length / Annulus Area (ft/in^2)	Heat Input (BTU/hr)	Sand Level
121-1S	3"	95'	1-1/4"	46'	0.233	0.4	8.80	40,000	18.4'
121-2S	"	"	"	"	0.291	"	"	50,000	"
121-3S	"	"	"	"	0.233	0.5	"	40,000	23.0'
121-4S	"	"	"	"	0.291	"	"	50,000	"
120-4B	"	"	1"	36'	0.291	0.560	5.97	57,700	20.0'
120-5B	"	"	"	"	0.276	"	"	54,800	"
120-6B	"	"	"	"	0.263	"	"	52,100	"
120-7B	"	"	"	"	0.249	"	"	49,500	"
120-8B	"	"	"	"	0.202	"	"	40,000	"
121-1B	"	"	"	46'	0.233	0.35	7.63	46,200	18.4'
121-2B	"	"	"	"	0.291	"	"	57,700	"
121-3B	"	"	"	"	0.233	0.44	"	46,200	23.0'
121-4B	"	"	"	"	0.291	"	"	57,700	"
121-5B	"	"	"	"	0.303	"	"	60,000	"
121-6B	"	"	"	"	0.253	"	"	50,000	"
122-1B	3-1/2"	130'	"	53.3'	0.233	0.51	6.25	65,000	27.2'
122-2B	"	"	"	"	0.291	"	"	82,100	"
122-3B	"	"	"	"	0.233	0.64	"	65,000	34.1'
122-4B	"	"	"	"	0.291	"	"	82,100	"
126-1	4"	160'	1-1/2"	"	0.233	0.400	5.39	75,800	27.3'
126-2	"	"	"	"	0.291	"	"	94,700	"
126-3	"	"	"	"	0.233	0.500	"	75,800	34.2'
126-4	"	"	"	"	0.291	"	"	94,700	"
127-1	"	"	"	30'	0.233	0.910	3.03	75,800	27.3'

Tests in Well 122 (Dc= 3.548")

Test	D_B	L_B (ft)	L_o (ft)	L_S (ft)	Sand Loss (in/day)	H (BTU/hr)	P_V (psig)	ΔP (psi)	G (lb/ft^{2}sec)	L_S/L_B	L_B/A_A (ft/in^2)	N_{Re}	N_{Rep}
122-1A	1.660"	53.3	3	21.3	4	59,250	35-37	21-23	.233	.400	6.90	1820	24.6
122-1c	"	"	"	"	"	59,390	35-37	21-23	.234	.400	"	1825	24.7
122-1d	"	"	"	"	"	58,910	35-37	21-23	.232	.400	"	1810	24.5
122-2a	"	"	"	"	1	74,480	41-45	21-25	.293	.400	"	2280	30.9
122-2b	"	"	"	"	1	73,420	41-42	22-23	.289	.396	"	2250	30.5
122-3a	"	"	"	26.7	8	59,230	40-42	26-28	.233	.502	"	1820	24.6
122-3b	"	"	"	24.5	"	59,330	39-41	25-27	.233	.460	"	1820	24.6
122-3c	"	"	"	26.7	"	59,160	40-43	26-29	.233	.502	"	1820	24.6
122-4	"	"	"	25.1	10	74,610	46-47-1/2	26-27-1/2	.294	.471	"	2290	31.0
123-2	"	68.1	"	20.5	3	74,450	42-46	22-26	.293	.301	8.82	2280	30.9
122-1Ba	1.315	53.3	11	23.7	6	66,470	29*	12*	.237	.445	6.25	2185	25.0
122-1Bb	"	"	"	23.1	6	66,190	29*	12*	.236	.443	"	2180	24.9
122-3Ba	"	"	"	29.6	14	65,775	39-40	22-23	.235	.555	"	2170	24.8
122-3Bb	"	"	"	30.0	"	66,390	35-39	18-22	.237	.563	"	2185	25.0
122-3Bc	"	"	"	29.0	"	65,610	37-42	20-25	.234	.544	"	2160	24.7

Tests in Well 124 (Dc= 4.026")

Test	D_B	L_B (ft)	L_o (ft)	L_S (ft)	Sand Loss (in/day)	H (BTU/hr)	P_V (psig)	ΔP (psi)	G (lb/ft^{2}sec)	L_S/L_B	L_B/A_A (ft/in^2)	N_{Re}	N_{Rep}
124-1a	1.900	68.3	3	38.7		76,000	54-58	34-38	.234	.567	6.92	2060	16.1
124-1b	"	"	"	38.7		76,000	54-58	34-38	.234	.567	"	2060	16.1
126-1a	"	53.3	19	28.6	20	77,700	43-45	22-24	.239	.537	5.39	2100	16.5
126-1b	"	"	"	27.9	"	77,700	42-44	21-23	.239	.524	"	"	"
126-1c	"	"	"	27.3	"	77,700	41-44	20-23	.239	.512	"	"	"
126-2a	"	"	3	26.4	12	95,550	45-47	21-23	.294	.495	"	2575	20.2
126-2b	"	"	"	25.1	"	95,450	44-48	20-24	.294	.471	"	2575	20.2
126-3	"	"	19	33.8	7	77,240	46-49	25-28	.238	.634	"	2090	16.4
126-4a	"	"	3	33.5	"	95,630	49-53	25-29	.294	.629	"	2590	20.2
126-4b	"	"	"	34.2	"	94,920	50-53	26-29	.292	.642	"	2570	20.1
127-1	"	30	19	26.4	8	76,990	38-41	17-20	.237	.880	3.03	2085	16.3
127-2	"	"	14	26.0	14	77,840	35-38	14-17	.240	.867	"	2110	16.5

* These pressure readings were not necessarily constant. Only the average pressure was reported.

TEST OPERATING CONDITIONS

Tests in Well 120 (Dc= 3.068 in.)

Test	D_B	L_B (ft)	L_o (ft)	L_S (ft)	Sand Loss (in/day)	H (BTU/hr)	P_v (psig)	ΔP (psi)	G (lb/ft^{2}sec)	L_S/L_B	L_B/A_A (ft/in^2)	Fuel	N_{Re}	N_{Rep}	D_B (in.)
120-1	1-1/4"	36	3	14.4	2	39,630	23-27	17-21	.231	.400	6.92	Propane	1345	20.5	1.660
120-2a	"	"	"	13.7	1	50,085	26-30	17-21	.291	.381	"	"	1690	25.7	"
120-2b	"	"	"	14.4	1	50,560	26-30	17-21	.294	.400	"	"	1710	26.0	"
120-3	"	"	"	18.0	5	40,764	30-32	24-26	.237	.500	"	"	1380	21.0	"
120-4	"	"	"	17.9	4	50,480	34-37	25-28	.294	.497	"	"	1710	26.0	"
121-1	"	46	"	18.4	1	40,800	33-35	27-29	.238	.400	8.80	"	1380	21.0	"
121-2	"	"	"	18.4	6	51,300	37-41	28-32	.299	.400	"	"	1740	26.4	"
121-3	"	"	"	22.7	4	41,300	38-41	32-35	.240	.493	"	"	1395	21.2	"
121-4	"	"	"	22.2	6	50,700	37-43	28-34	.295	.483	"	"	1710	26.0	"
120-4B	1"	36	8	17.8	20	58,560	32-36	21-25	.296	.494	5.97	"	2140	26.2	1.315
120-8B	"	"	"	20.0	1	40,000	30-34	24-28	.202	.555	"	"	1460	17.9	"
120-9B*	"	"	"	20.0	1	40,000	30-34	24-28	.202	.555	"	"	1460	17.9	"
121-1B	"	46	2	15.9	2	47,000	30	21	.237	.346	7.63	"	1720	21.0	"
121-2Ba	"	"	8	14.8	8	58,850	30-33	19-22	.296	.322	"	"	2145	26.2	"
121-2Bb	"	"	"	13.0	8	59,180	30-33	19-22	.299	.283	"	"	2170	26.5	"
121-3B	"	"	"	20.2		46,200	33-35	25-27	.233	.437	"	"	1690	20.6	"
121-6Ba	"	"	"	19.0	6	49,900	33-36	24-27	.252	.413	"	"	1825	22.3	"
121-6Bb	"	"	"	19.9	6	49,200	32-36	22-26	.248	.433	"	"	1800	21.9	"
121-1Sa	1-1/4"	"	5	18.4		40,664			.226	.400	8.80	Prod.Gas	1315	20.0	1.660
121-1Sb	"	"	5	21.0		40,580			.226	.457	"	"	1315	20.0	"
121-1Sc	"	"	7	18.4		40,944			.228	.400	"	"	1330	20.2	"
121-2S	"	"	7	18.1		50,950			.283	.394	"	"	1645	25.0	"
121-3Sa	"	"	3	23.0		40,570	36-38	30-32	.225	.500	"	"	1310	19.9	"
121-3Sb	"	"	"	23.0		40,830	34-37	28-31	.227	.500	"	"	1320	20.1	"
121-4S	"	"	"	22.7		51,100	39-41	31-33	.284	.493	"	"	1650	25.1	"
121-3BSa	1"	"	8	19.5		50,000	36-39	28-31	.242	.424	7.63	"	1750	21.4	1.315
121-3BSb	1"	"	8	19.3		46,200			.223	.420	7.63	"	1620	19.8	1.315

* 120-9B was the same as 120-8B with a baffle placed 25' from the surface on the supply pipe.

Table 5

PRELIMINARY BURNER TEST RESULTS

Test No.	1	3	2	3A	1A
Date	8/18-22	8/28-30	8/30-9/3	9/3-6	9/6-8
Sand Level	18.4	18.4	23.4	17.0	18.4
Heat Input	46,000	58,600	46,000	58,600	46,000
Flow Rate	.269	.342	.269	.342	.269
L_S/L_B	.511	.511	.650	.472	.511
Sand Life at start (hr)	112	324	367 ⊕	462	533
L_{HS}	59	70	71	81	65
L_H	46	53	57	55	51
L_{HS}/L_S	3.2	3.8	3.0	4.8	3.5
L_H/L_S	2.5	2.9	2.4	3.2	2.8
$L_{HS} - L_H$	13	17	14	26	14

⊕ Sand Sample Taken (see Figure 2)

Table 6

TEST RESULTS

Test	ΔT_{max} (°F)	ΔT_{avg} (°F)	T_E (°F)	E (%)	L_H (ft)	L_H' (ft)	L_H'/L_S	H_A BTU/hr ft	H_S
Well 120									
120-1	505	436	150	86.2	54-1/2	54-1/2	3.78	571	0.785
120-2a	520	457	150	87.9	59	59	4.30	689	0.799
120-2b	565	501	150	88.6	61	61	4.23	665	0.802
120-3	550	460	140	83.7	57-1/2	57-1/2	3.19	559	0.792
120-4	545	462	120	84.7	65-1/2	65-1/2	3.66	639	0.829
121-1	575	447	150	77.7	61-1/2	61-1/2	3.34	526	0.794
121-2	630	507	175	80.4	68	68	3.69	608	0.806
121-3	585	455	110	77.8	69	69	3.04	499	0.833
121-4	595	465	210	78.2	72	72	3.21	562	0.800
120-4B	610	520	150	85.3	66	66	3.71	685	0.771
120-8B	510	428	220	84.0	63-1/2	63-1/2	3.17	465	0.738
120-9B	485	424	220	87.5	64-1/2	64-1/2	3.22	460	0.742
121-1B	580	453	160	78.1	64-1/2	64-1/2	4.05	571	0.784
121-2Ba	650	524	205	80.6	70-1/2	70-1/2	4.76	685	0.821
121-2Bb	665	543	225	81.7	69-1/2	69-1/2	5.35	690	0.810
121-3B	560	443	215	79.1	64	64	3.18	569	0.788
121-6Ba	600	464	195	77.5	73	73	3.84	570	0.833
121-6Bb	575	441	220	76.7	72-1/2	72-1/2	3.64	552	0.813
121-1Sa	565	367	145	65.0	55-1/2	55-1/2	3.02	544	0.743
121-1Sb	540	382	155	70.7	58	58	2.76	528	0.755
121-1Sc	585	407	165	69.6	54-1/2	54-1/2	2.96	552	0.734
121-2S	625	450	140	72.1	63-1/2	63-1/2	3.50	654	0.815
121-3Sa	475	352	130	74.2	62-1/2	62-1/2	2.72	534	0.822
121-3Sb	525	380	150	72.4	60-1/2	60-1/2	2.63	522	0.774
121-4S	575	439	150	76.4	67-1/2	67-1/2	2.97	606	0.800
121-3BSa	565	427	220	75.6	69	69	3.54	570	0.787
121-3BSb	550	431	220	78.3	68-1/2	68-1/2	3.55	531	0.788

Table 6 - TEST RESULTS (continued)

Test	ΔT_{max} (°F)	ΔT_{avg} (°F)	T_E (°F)	E (%)	L_H (ft)	L_H' (ft)	L_H'/L_S	H_A BTU/hr ft	H_S
Well 122									
122-1a	380	271	150	71.4	71-1/2	71-1/2	3.35	641	0.773
122-1c	355	261	150	73.6	71	71	3.33	634	0.757
122-1d	365	273	150	74.9	73	73	3.42	626	0.776
122-2a	425	321	150	75.6	83-1/2	83-1/2	3.92	707	0.792
122-2b	400	309	150	77.2	84	84	3.98	698	0.799
122-3a	380	267	160	70.1	81-1/2	81-1/2	3.05	570	0.784
122-3b	400	273	160	68.2	81-1/2	81-1/2	3.33	572	0.786
122-3c	390	272	160	69.6	82	82	3.07	570	0.790
122-4	405	302	125	74.6	95	95	3.79	654	0.832
123-2	500	381	200	76.2	64	94	4.58	728	0.626
122-1Ba	515	418	130	81.1	76-1/2	96	4.05	659	0.770
122-1Bb	530	411	140	77.6	79-1/2	96-1/2	4.18	645	0.774
122-3Ba	540	404	180	74.7	75-1/2	93	3.14	630	0.723
122-3Bb	510	428	250	84.0	76-1/2	96-1/2	3.22	635	0.732
122-3Bc	510	416	170	81.5	77-1/2	94-1/2	3.26	625	0.739
Well 124									
124-1a	840	730	300	86.8	85-1/2	108-1/2	2.80	602	0.676
124-1b	900	751	300	83.5	85	109	2.82	604	0.676
126-1a	375	320	150	85.5	79	79	2.76	745	0.757
126-1b	380	325	150	88.2	74-1/2	74-1/2	2.67	785	0.752
126-1c	410	348	230	84.8	83	83	3.04	649	0.693
126-2a	450	373	225	83.0	92	92	3.48	739	0.712
126-2b	440	383	225	87.0	93-1/2	93-1/2	3.72	738	0.723
126-3	445	347	225	78.1	90	90	2.66	628	0.731
126-4a	450	356	225	79.1	101	101	3.01	698	0.738
126-4b	435	349	225	80.3	101	101	2.96	701	0.746
127-1	435	366	220	84.0	79-1/2	79-1/2	3.01	678	0.700
127-2	505	410	150	81.3	64	64	2.46	802	0.660

Table 7

PRESSURE DROP DATA

WELL 120

Test	$\Delta P/L_S$	N_{Re}	N_{Rep}	r_h
120-1	1.320	1340	20.4	0.352
2	1.387	1690	25.7	"
3	1.39	1380	20.9	"
4	1.48	1710	26.0	"
121-1a	1.51	1360	20.7	"
1b	1.52	1380	20.9	"
2	1.60	1720	26.2	"
3a	1.48	1400	21.2	"
3b	1.43	1390	21.1	"
4a	1.41	1710	26.0	"
4b	1.33	1720	26.2	"
4c	1.43	1710	26.0	"
121-3Sa	1.35	1310	19.9	0.352
3Sb	1.29	1320	20.1	"
4S	1.41	1650	25.1	"
121-3BS	1.51	1750	21.4	0.439
120-4B	1.29	2140	26.2	0.439
8B	1.30	1460	17.9	"
9B	1.30	1460	17.9	"
121-1B	1.32	1720	21.0	"
2Ba	1.38	2140	26.2	"
2Bb	1.58	2170	26.4	"
3B	0.89	1690	20.6	"
6Ba	1.34	1830	22.3	"
6Bb	1.20	1800	21.9	"

WELL 122

Test	$\Delta P/L_S$	N_{Re}	N_{Rep}	r_h
122-1a	1.032	1820	24.4	0.472
1c	1.032	1820	24.6	"
1d	1.032	1810	24.4	"
2a	1.080	2280	30.7	"
2b	1.066	2250	30.3	"
3a	1.011	1820	24.4	"
3b	1.060	1820	24.4	"
3c	1.030	1820	24.4	"
4	1.065	2290	30.8	"
123-2	1.170	2280	30.7	"
122-1Ba	0.506	2190	24.9	0.5585
1Bb	0.520	2180	24.8	"
3Ba	0.760	2170	24.7	"
3Bb	0.667	2190	24.9	"
3Bc	0.776	2160	24.6	"

Table 7 (continued)

PRESSURE DROP DATA

WELL 124

Test	$\Delta P/L_S$	N_{Re}	N_{Rep}	r_h
124-1	0.930	2060	16.1	0.5315
126-1a	0.804	2100	16.4	"
1b	0.789	2100	16.4	"
1c	0.787	2100	16.4	"
2a	0.833	2590	20.2	"
2b	0.877	2590	20.2	"
3	0.782	2090	16.4	"
4a	0.806	2590	20.2	"
4b	0.804	2570	20.1	"
127-1	0.702	2080	16.3	"
2a	0.597	2110	16.5	"
2b	0.618	2100	16.4	"

Table 8

AIR FLUIDIZATION DATA - WELL 120

d_p = 0.0316 inch

Flow Rate (scf/hr)	Sand Level: 5.08 ft P_Y (psig)	ΔP (psi)	Sand Level: 10.7 ft P_Y (psig)	ΔP (psi)	Sand Level: 15.05 ft P_Y (psig)	ΔP (psi)	Sand Level: 18.4 ft P_Y (psig)	ΔP (psi)
612	13.0 - 14.6	1.9 - 3.5	18.3 - 20.5	7.2 - 9.1	23.5 - 24.6	11.9 - 13.0	26.2 - 27.2	14.6 - 15.
585	12.6 - 13.5	2.2 - 3.1						
557	11.6 - 13.3	2.0 - 3.7	17.5 - 19.4	7.9 - 9.8	21.8 - 22.8	11.7 - 12.7	24.6 - 26.3	14.5 - 16.
532	11.2 - 12.4	2.3 - 3.5						
508	10.5 - 11.8	2.2 - 3.5	16.0 - 17.5	7.7 - 9.2	20.3 - 21.5	11.5 - 12.7	23.6 - 24.5	14.8 - 15.
484	10.1 - 11.2	2.4 - 3.5						
463	9.8 - 11.0	2.6 - 3.8	15.5 - 16.6	8.4 - 9.5	19.6 - 20.5	12.0 - 12.9	22.5 - 23.3	14.9 - 15.
441	9.6 - 10.4	3.0 - 4.4	14.6 - 15.8	8.0 - 9.2	19.0 - 20.0	11.9 - 12.9	21.8 - 22.6	14.7 - 15.
419	8.6 - 9.6	2.5 - 3.5	14.3 - 15.0	8.2 - 8.9	18.2 - 19.9	11.6 - 13.3	20.8 - 21.4	14.2 - 14.
397	8.3 - 9.8	2.6 - 4.1	13.8 - 14.4	8.2 - 8.8	17.4 - 17.8	11.3 - 11.7	19.7 - 20.0	13.6 - 13.
374	8.3 - 8.6	3.2 - 3.5	13.5 - 13.8	8.4 - 8.7	17.0 - 17.2	11.4 - 11.6	19.4 - 19.6	13.7 - 13.
350	7.6 - 8.1	3.0 - 3.5	13.0 - 13.3	8.4 - 8.7	16.2 - 16.4	11.2 - 11.4	18.4 - 18.5	13.4 - 13.
326	7.2 - 7.4	3.0 - 3.2	12.2 - 12.4	8.1 - 8.3	14.9 - 15.0	10.5 - 10.6	17.0	12.6
302	7.1	3.5	11.2 - 11.4	7.6 - 7.8	13.9 - 14.0	10.0 - 10.1	15.6	11.7
279	6.3	3.1	10.5	7.3	12.9	9.5	14.5	11.1
253	5.9	3.2	9.9	7.2	11.7	8.8	13.5	10.6
227	5.3	3.1	8.9	6.7	10.4	8.1	12.0	9.6
201	4.6	2.4	7.9	6.1	9.4	7.5	11.0	9.1
174	3.9	2.4	6.8	5.4	8.8	6.8	9.8	8.3
148	3.3	2.1	5.8	4.7	7.5	6.3	8.4	7.3
121	2.6	1.7	4.7	3.9	6.0	5.2	6.8	6.0
108	2.2	1.4	4.1	3.4	5.3	4.6	6.0	5.3
98	1.6	1.0	3.4	2.8	4.4	3.8	5.1	4.5
82	1.4	1.0	2.7	2.3	3.5	3.1	4.1	3.7
68	1.05	0.7	2.0	1.7	2.6	2.3	3.1	2.9
55	0.48	0.3	1.3	1.1	1.7	1.5		
42	0.43	0.2	0.85	0.7	1.1	1.0	1.3	1.2
15	0.39	0.2						
6	0.35	0.2						

Table 8 (continued)

AIR FLUIDIZATION DATA - WELL 120

d_p = 0.0260 inch   Sand Used 367 Hours

Sand Level: 20.0 ft

Flow Rate (scf/hr)	P_Y (psig)	ΔP (psi)
715	34.0 - 39.5	17.0 - 22.5
602	30.0 - 35.1	16.5 - 21.6
541	29.0 - 35.2	17.0 - 23.2
502	29.5 - 33.5	18.7 - 22.7
447	26.6 - 31.6	17.5 - 22.5
410	26.0 - 30.0	18.0 - 22.0
356	25.0 - 28.0	18.6 - 21.6
292	23.3 - 26.0	18.3 - 21.0
275	22.8 - 24.0	18.8 - 20.0
237	22.0 - 23.0	18.7 - 19.7
204	20.2 - 21.0	17.6 - 18.4
174	16.5	14.6
143	14.5	13.5
108	6.8	6.2

Sand Level: 23.4 ft

Flow Rate (scf/hr)	P_Y (psig)	ΔP (psi)
662	35.0 - 40.8	20.6 - 26.4
574	31.0 - 38.0	18.0 - 23.0
513	31.5 - 37.9	20.5 - 26.0
470	30.0 - 35.0	20.2 - 25.2
408	29.9 - 34.3	21.9 - 26.3
382	28.5 - 33.0	21.3 - 25.8
359	28.8 - 31.8	22.3 - 25.3
325	27.5 - 31.0	22.1 - 25.6
295	28.4 - 30.8	23.8 - 26.2
265	26.8 - 28.5	22.9 - 24.6
235	25.9 - 27.1	22.7 - 23.9
200	23.5 - 24.9	21.0 - 22.4
172	21.9 - 22.9	19.9 - 20.9
140	20.0 - 21.0	18.6 - 19.6
109	17.7	16.7
83	13.5	12.8
53	8.0	7.6
23	7.5	7.4

Table 8 (continued)

AIR FLUIDIZATION DATA - WELL 122

New Sand: $d_p = 0.316$ inch

	Sand Level: 10.0 ft.		Sand Level: 20.0 ft.	
Flow Rate (scf/hr)	P_Y (psig)	ΔP (psi)	P_Y (psig)	ΔP (psi)
724	23.6 - 24.3	4.4 - 5.1	30.0 - 31.6	10.8 - 12.4
650	21.6 - 22.0	5.3 - 5.7	28.0 - 28.4	11.7 - 12.1
580	19.0 - 19.9	5.6 - 6.5	25.9 - 26.5	12.5 - 13.1
512	17.2 - 17.8	5.6 - 6.2	23.2 - 23.6	11.6 - 12.0
444	15.4 - 15.6	5.5 - 5.7	21.1 - 21.2	11.2 - 11.3
378	13.5	5.6	18.5 - 18.7	10.6 - 10.8
316	11.4	5.6	15.8 - 16.0	10.0 - 10.2
260	9.1	4.7	13.0 - 13.2	8.6 - 8.8
200	7.0	4.0	10.0	7.0
137	4.0	2.5	6.5	5.0

WELL 124

New Sand: $d_p = 0.0316$ inch

	Sand Level: 27.5 ft.	
Flow Rate (scf/hr)	P_Y (psig)	ΔP (psi)
646	25.8	9.6
580	23.5	10.0
515	21.0	9.2
446	18.0	8.1
350	16.0	8.9
320	13.4	7.3
267	10.8	6.2
214	8.0	4.7
140	4.5	3.0

Table 9

SIEVE ANALYSES IN WELL 120

		Weight Percent on Sieve			
Tyler Sieve	Opening (in.)	Original Sand	(8-30-58) After 367 hrs.	(9-18-58) After 800 hrs.	(3-20-59) End of Tests
+ 20	0.0328	44.70	24.10	19.21	23.00
20 - 28	0.0232	45.50	40.85	36.00	40.54
28 - 35	0.0164	7.60	21.00	23.22	19.40
35 - 48	0.0116	1.30	10.33	14.04	9.94
48 - 65	0.0082	0.60	3.28	5.64	4.89
65 - 100	0.0058	0.20	0.29	1.45	1.25
100 - 150	0.0041	0.06	0.06	0.40	0.55
150 - 200	0.0029	0.04	0.05	0.04	0.25
200 - 250	0.0024	0.00	0.01	0.00	0.08
Pan		0.00	0.03	0.00	0.10
Average Particle Diameter (in.)		0.0316	0.0260	0.0239	0.0214

Table 10

SIEVE ANALYSES AT END OF TESTS

Tyler Sieve	Opening (in.)	Weight Percent on Sieve		
		Well 120	Well 122	Well 124
+ 20	0.0238	23.00	33.53	11.61
20 - 28	0.0232	40.54	37.77	24.08
28 - 35	0.0164	19.40	19.74	25.63
35 - 48	0.0116	9.94	7.86	21.41
48 - 65	0.0082	4.89	0.95	13.51
65 - 100	0.0058	1.25	0.08	3.00
100 - 150	0.0041	0.55	0.03	0.45
150 - 200	0.0029	0.25	0.02	0.20
200 - 250	0.0024	0.08	0.005	0.04
Pan		0.10	0.015	0.07
Average Particle Diameter (in.)		0.0214	0.0255	0.0167

Table 11

PRODUCED GAS ANALYSES

(Sampled January 23, 1959)

Component	Separator Gas	Sweetened Gas
H_2	44.5% (vol.)	43.2% (vol.)
H_2S	5.7	0.0
CO_2	3.1	3.5
$CO + N_2$	0.1	3.9
CH_4	33.8	33.3
C_2H_6	5.0	4.8
C_3H_8	2.4	2.6
iC_4H_{10}	0.6	0.8
nC_4H_{10}	0.8	1.0
iC_5H_{12}	0.1	0.0
nC_5H_{12}	0.4	1.2
C_2H_4	0.7	1.0
C_3H_6	0.6	0.6
C_4H_8	1.0	1.5
C_5H_{10}	0.7	1.3
C_3H_4	0.1	0.2
C_4H_6	0.0	0.1
Av. C_6	0.4	1.0
Heat of Combustion (gross)	843 BTU/scf	922 BTU/scf
Specific Gravity	0.528	0.578

SUMMARY OF REGRESSION ANALYSIS RESULTS

LENGTH OF HEATED INTERVAL

No. of Data Points: 55

Mean L_H = 72.68 feet

ΣL_H^2 = 297,819.75

$$L_H = a_0 + a_1 L_B + a_2 \frac{L_S}{L_B} + a_3 \frac{L_B}{A_A} + a_4 D_c + a_5 G + a_6 F + a_7 D_c \sqrt{G}$$

Trial No.:	1 ⊕⊕	4	10
a_0	72.9	20.50	8.10
a_1	0.764	0.739	0.755
a_2	48.5	43.8	44.8
a_3	- 4.35	- 3.90	- 4.03
a_4	-89.3	0.706 ⊕	-
a_5	-423 ⊕	140	141
a_6	- 1.40 ⊕	-	-
a_7	172	-	-
t_1	6.06	5.74	10.9
t_2	4.05	3.46	4.41
t_3	3.26	3.20	5.30
t_4	2.47	0.141 ⊕	-
t_5	1.79 ⊕	5.23	5.57
t_6	0.57 ⊕	-	-
t_7	2.40	-	-
σ	$\pm$ 5.01	$\pm$ 5.32	$\pm$ 5.27

From 10c:

$$L_H = 8.10 + 141G + 0.755L_B + 44.8 \frac{L_S}{L_B} - 4.03 \frac{L_B}{A_A}$$

⊕ a_i not significantly different from zero

⊕⊕ In Trial No. 1, some data points were in error, but not enough to change the results significantly.

Table 13

SUMMARY OF REGRESSION ANALYSIS RESULTS

ACTUAL HEAT INPUT, H_A

No. of Data Points: 55

Mean H_A: 619.9 BTU/ft hr

$\Sigma H_A{}^2 = 214{,}681.83$

$$H_A = a_0 + a_1 \frac{L_S}{L_B} + a_2 G + a_3 D_c + a_4 L_B + a_5 F + a_6 \frac{L_B}{A_A} + a_7 D_c \sqrt{G}$$

Trial No.:	1	2	3
a_0	-1449	98.4	-61.8
a_1	- 407	- 404	- 394
a_2	5200	1310	1220
a_3	772	179	213
a_4	-2.34	-2.61	-3.49
a_5	39.3	30.1 ⊕	-
a_6	-18.6	-15.8 ⊕	-
a_7	-1180	-	-
t_1	5.65	5.25	5.05
t_2	3.65	7.90	7.41
t_3	3.54	5.82	10.7
t_4	3.08	3.26	5.78
t_5	2.64	1.95 ⊕	-
t_6	2.31	1.83 ⊕	-
t_7	2.74	-	-
σ	30.2	32.8	34.6

From Trial No. 3:

$$H_A = -61.8 + 213D_c - 3.49L_B + 1222G - 394 \frac{L_S}{L_B}$$

⊕ a_i Not significantly different from zero

Table 14

SUMMARY OF REGRESSION ANALYSIS RESULTS

TEMPERATURE RATIO, E.

No. of Data Points: 55

Mean E: 79.01%

$\Sigma E^2 = 345{,}114$

$$E = a_0 + a_1 D_c + a_2 L_B + a_3 G + a_4 \frac{L_S}{L_B} + a_5 \frac{L_B}{A_A} + a_6 F + a_7 D_c \sqrt{G}$$

Trial No.:	1	6	11	15
a_0	57.22	82.9	89.8	117.1
a_1	25.8 ⊕	-	-	- 4.82 ⊕
a_2	0.124 ⊕	-	-	-
a_3	271 ⊕	30.8 ⊕	-	-
a_4	6.85 ⊕	-	-	-
a_5	- 3.54	- 1.58	- 1.44	- 3.11
a_6	- 3.15 ⊕	- 4.09 ⊕	- 4.81	-
a_7	-69.2 ⊕	-	-	-
t_1	0.77 ⊕	-	-	1.95 ⊕
t_2	1.07 ⊕	-	-	-
t_3	1.24 ⊕	1.36 ⊕	-	-
t_4	0.62 ⊕	-	-	-
t_5	2.88	2.79	5.62	4.44
t_6	1.38 ⊕	1.95 ⊕	5.16	-
t_7	1.05 ⊕	-	-	-
σ	± 4.62	± 4.75	± 4.79	± 4.87

From Trial No. 11:

$$E = 89.8 - 1.44 \frac{L_B}{A_A} - 4.81F$$

⊕ a_i Not significantly different from zero.

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Table 15

SUMMARY OF REGRESSION ANALYSIS RESULTS

BED EXPANSION, L_H'/L_S

No. of Data Points: 55

Mean L_H'/L_S: 3.411

$\sum (L_H'/L_S)^2$: 657.57

$$L_H'/L_S = a_0 + a_1 \frac{L_S}{L_B} + a_2 \frac{L_B}{A_A} + a_3 G + a_4 F + a_5 D_c + a_6 L_B + a_7 D_c \sqrt{G}$$

Trial No.	$1^{\oplus\oplus}$	7	12	16
a_0	4.937	1.52	5.04	7.93
a_1	- 4.34	- 4.70	- 4.38	- 4.68
a_2	- 0.337	- 0.171	- 0.268	- 0.315
a_3	21.3 $^{\oplus}$	6.24	6.94	7.31
a_4	- 0.202 $^{\oplus}$	- 0.193 $^{\oplus}$	- 0.219 $^{\oplus}$	-
a_5	1.52 $^{\oplus}$	-	- 0.581	- 0.568
a_6	0.00381 $^{\oplus}$	-	-	-
a_7	- 4.54 $^{\oplus}$	-	-	-
t_1	5.90	7.82	8.27	9.19
t_2	4.10	3.11	5.04	6.70
t_3	1.47 $^{\oplus}$	4.11	5.22	5.48
t_4	1.33 $^{\oplus}$	1.33 $^{\oplus}$	1.74 $^{\oplus}$	-
t_5	0.68 $^{\oplus}$	-	4.17	3.97
t_6	0.49 $^{\oplus}$	-	-	-
t_7	1.03 $^{\oplus}$	-	-	-
σ	$\pm$ 0.308	$\pm$ 0.310	$\pm$ 0.270	$\pm$ 0.275

From 16:

$$L_H'/L_S = 7.93 - 4.68 \frac{L_S}{L_B} - 0.315 \frac{L_B}{A_A} + 7.31G - 0.568D_c$$

$\oplus$ a_i not significantly different from zero

$\oplus\oplus$ In trial No. 1, some data points were in error, but results were not changed significantly

Table 16

SUMMARY OF REGRESSION ANALYSIS RESULTS

HEAT INPUT RATIO, H_R

Mean $H_R = 0.7671$

$\Sigma H_R^2 = 32.480$

$$H_R = a_0 + a_1 D_c + a_2 L_B + a_3 G + a_4 \frac{L_S}{L_B} + a_5 \frac{L_B}{A_A} + a_6 F$$

Trial No.	1	17
a_0	1.04	0.952
a_1	- 0.0986	- 0.0796
a_2	0.000503 ⊕	-
a_3	0.316 ⊕	0.342
a_4	- 0.00829 ⊕	-
a_5	- 0.00505 ⊕	-
a_6	- 0.0105 ⊕	-
t_1	2.99	6.72
t_2	0.585 ⊕	-
t_3	1.78 ⊕	2.19
t_4	0.100 ⊕	-
t_5	0.554 ⊕	-
t_6	0.632 ⊕	-
σ	$\pm$ 0.0345	$\pm$ 0.0338

From Trial No. 17:

$$H_R = 0.952 - 0.0796\, D_c + 0.342\, G$$

⊕ a_i not significantly different from zero

Table 17

SUMMARY OF REGRESSION ANALYSIS RESULTS

PRESSURE DROP, $\Delta P/L_S$

Number of Data Points: 49

Mean $\Delta P/L_S$ = 1.136 psi/ft.

$\Sigma(\Delta P/L_S)^2 = 67.428644$

$$\Delta P/L_S = a_0 + a_1 N_{Rep} + a_2 r_h$$

Trial No.	14	18
a_0	2.631	2.73
a_1	0.0819 ⊕	-
a_2	- 1.58	- 3.55
t_1	0.740 ⊕	-
t_2	14.2	22.9
σ	± 0.1279	± 0.1302

From Trial No. 18:

$$\Delta P/L_S = 2.73 - 3.55\ r_h$$

⊕ a_1 not significantly different from zero

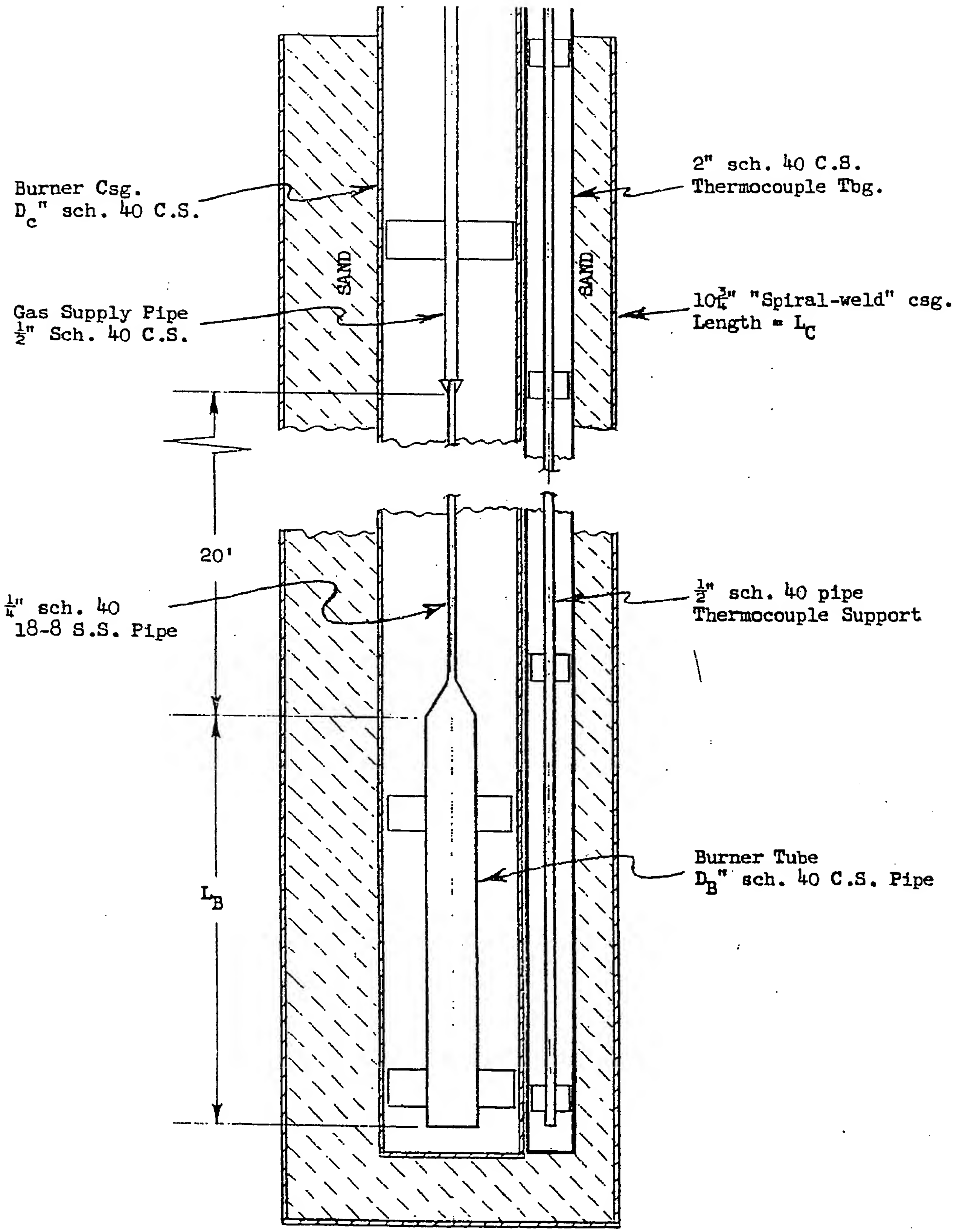
200 300 FLOW

Table 18

RANGES AND MEANS OF VARIABLES

IN BURNER TESTS

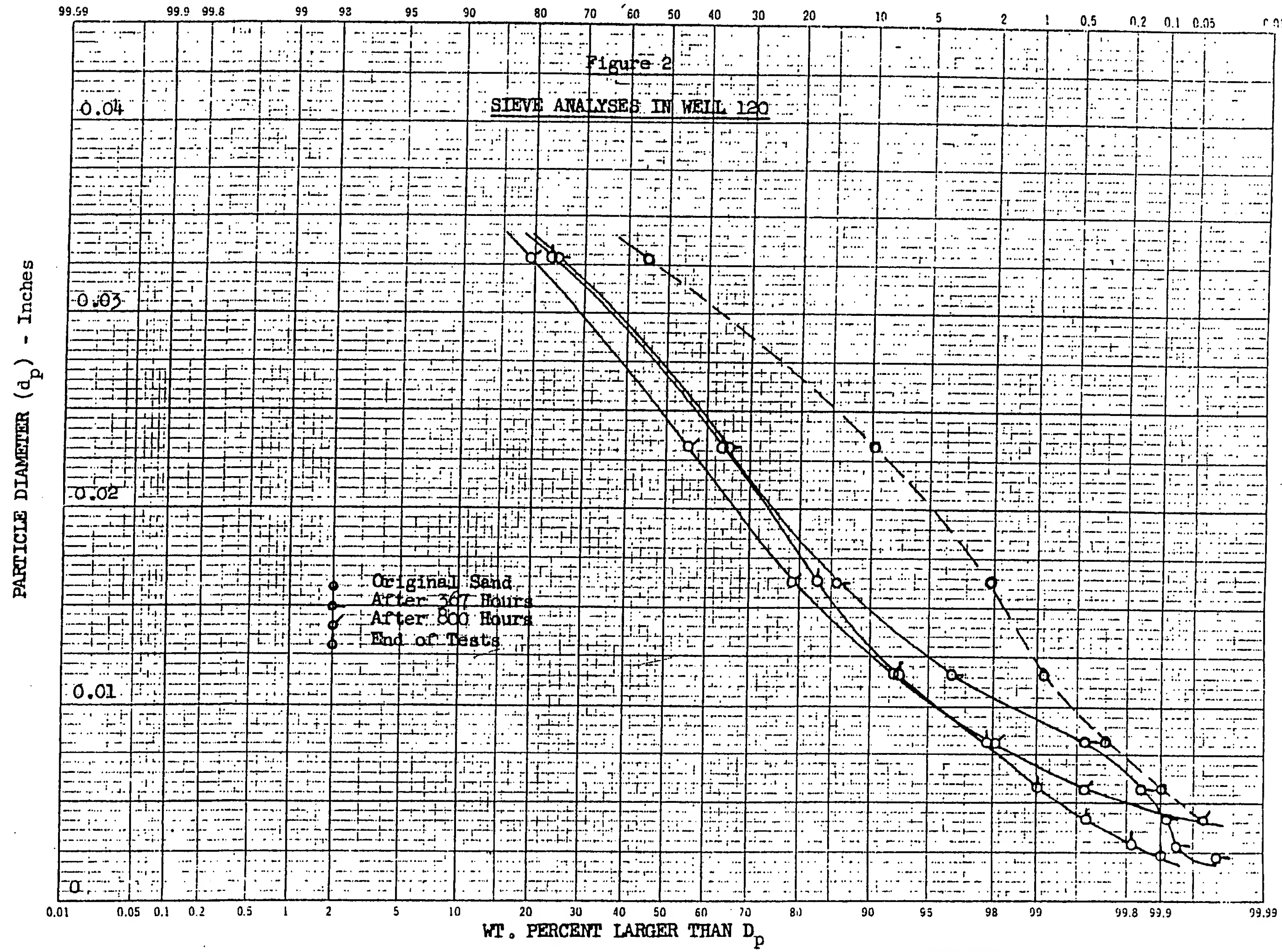
Variable	Minimum	Maximum	Mean
r_h (in)	0.352	0.559	0.448
L_B (ft)	30	68	46.9
L_S/L_B	0.283	0.880	0.480
G ($lb/ft^2 sec$)	0.202	0.299	0.253
L_B/A_A (ft/in^2)	3.03	8.82	6.95
D (in)	3.068	4.026	3.408
H_A (BTU/ft hr)	460	802	620
H_R	0.626	0.833	0.767
E	65.0	88.6	79.0
L_H'/L_S	2.46	5.35	3.41
L_H (ft)	$54\frac{1}{2}$	101	72.7
$\Delta P/L_S$ (psi/ft)	0.506	1.60	1.14


Burner Csg.
D_c" sch. 40 C.S.
2" sch. 40 C.S.
Thermocouple Tbg.
SAND
SAND
Gas Supply Pipe
½" Sch. 40 C.S.
10¾" "Spiral-weld" csg.
Length = L_C
20'
¼" sch. 40
18-8 S.S. Pipe
½" sch. 40 pipe
Thermocouple Support
Burner Tube
D_B" sch. 40 C.S. Pipe
L_B

FLOW

Figure 2

SIEVE ANALYSES IN WELL 120



FLOW R

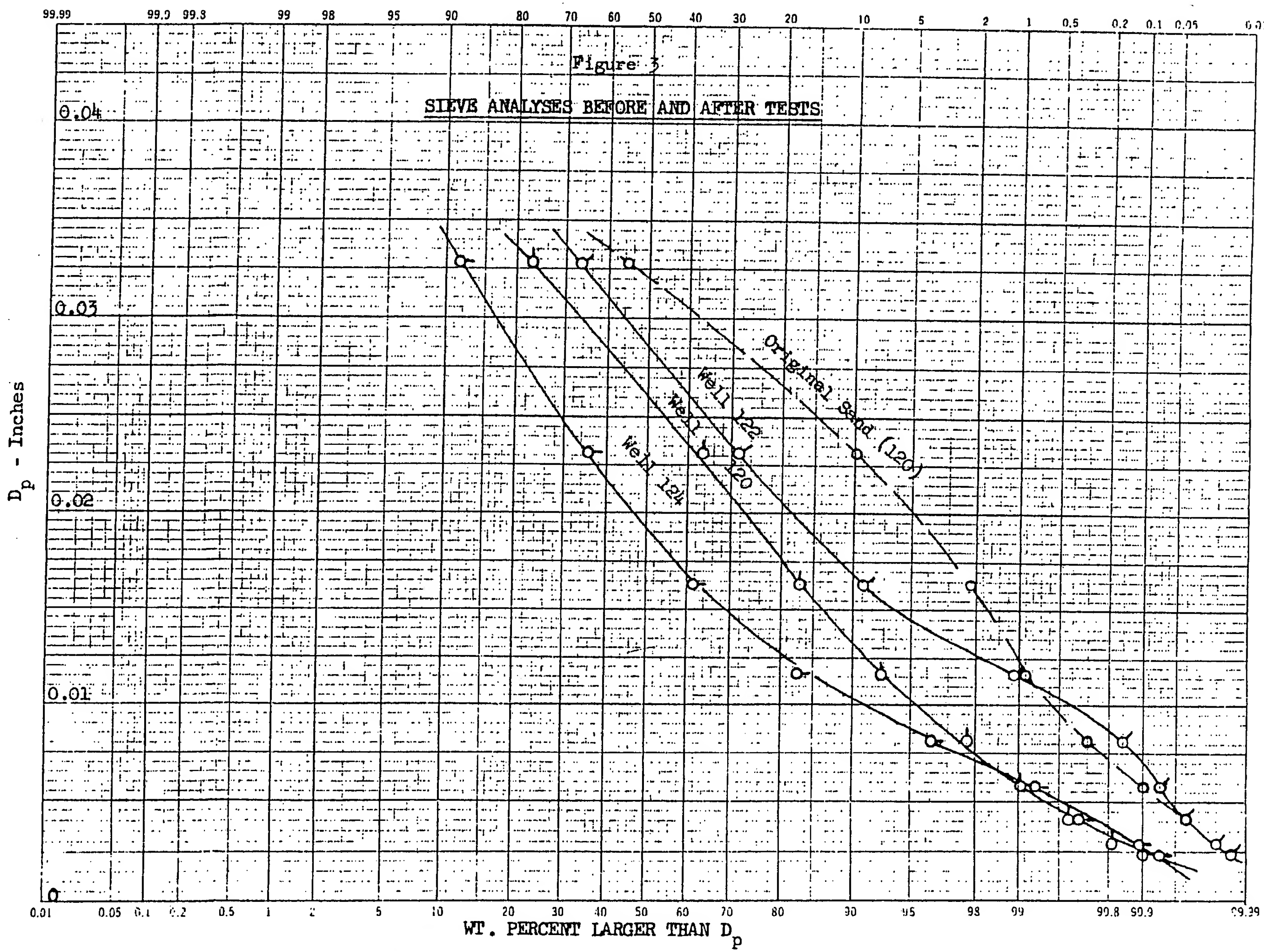
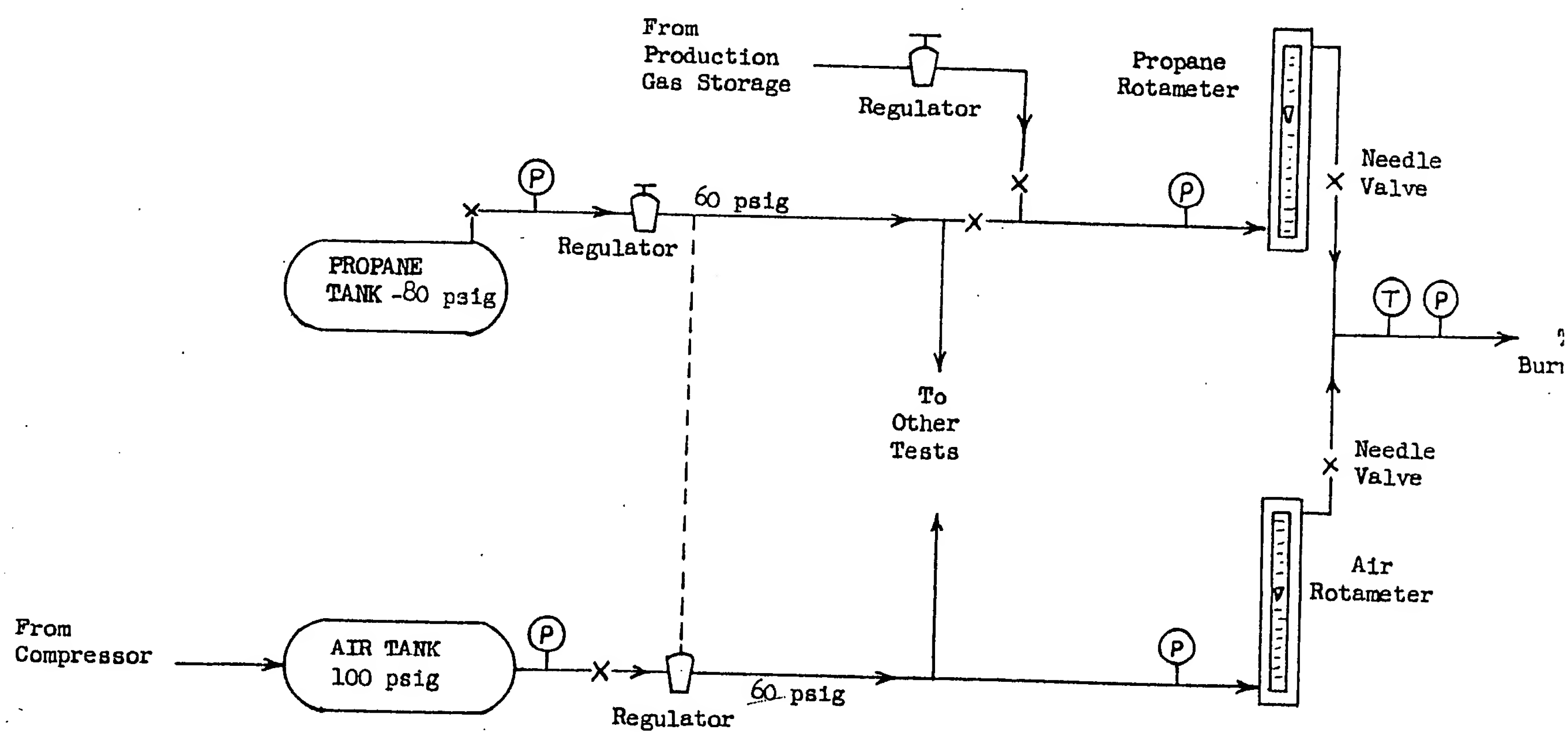


Figure 3
SIEVE ANALYSES BEFORE AND AFTER TESTS
Original Sand (120)
Well 122
Well 120
Well 124
D_p - Inches
0.04
0.03
0.02
0.01
WT. PERCENT LARGER THAN D_p

Figure 4

FLOW DIAGRAM OF FUEL SUPPLY SYSTEM



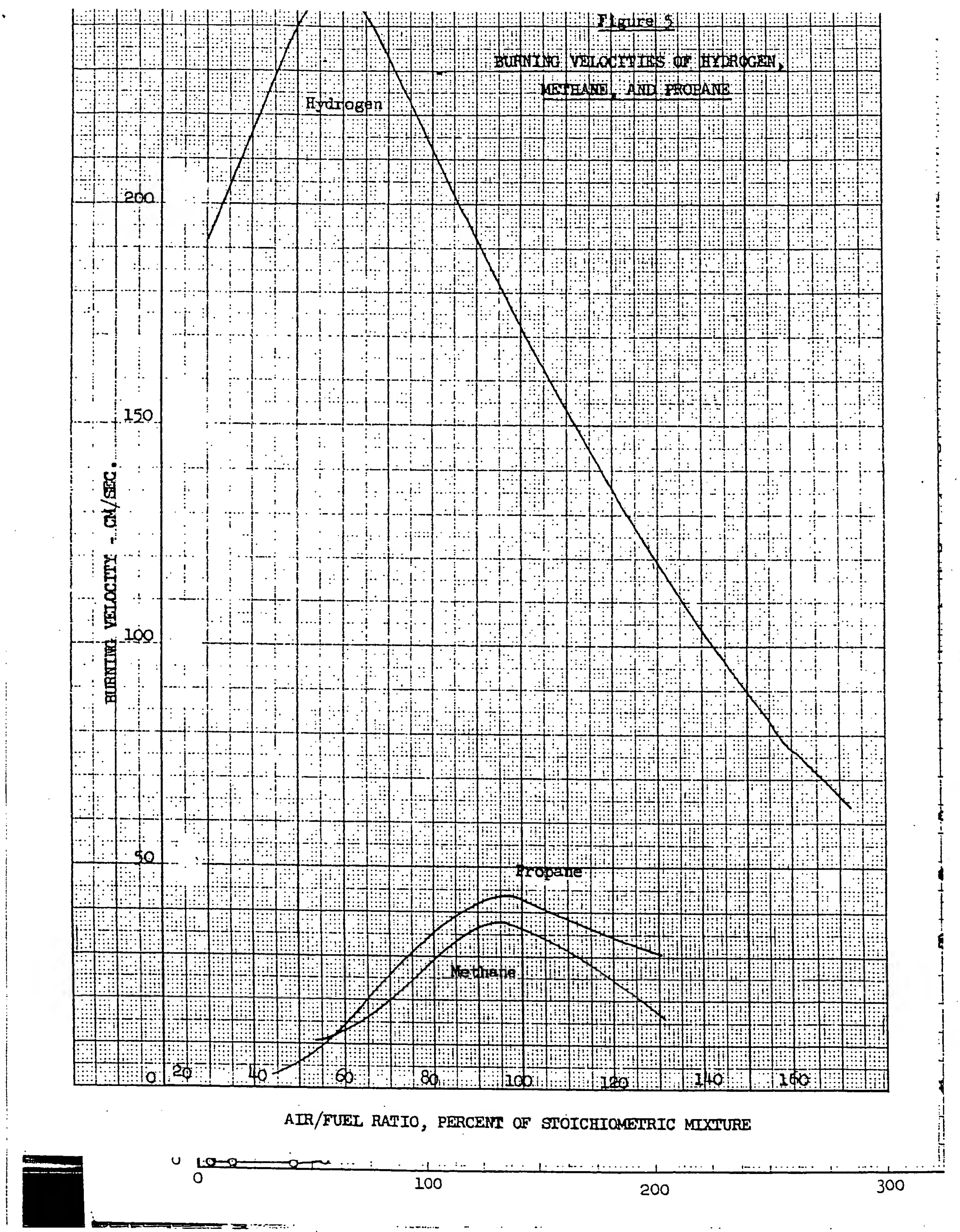


Figure 5
BURNING VELOCITIES OF HYDROGEN, METHANE, AND PROPANE
Hydrogen
Propane
Methane
BURNING VELOCITY - CM/SEC.
200
150
100
50
0
20
40
60
80
100
120
140
160
AIR/FUEL RATIO, PERCENT OF STOICHIOMETRIC MIXTURE
0
100
200
300

Figure 6

PRESSURE DROP ACROSS FLUID BED VS. AIR FLOW RATE

WELD 120

(D_c = 3.068", D_B = 2.660")

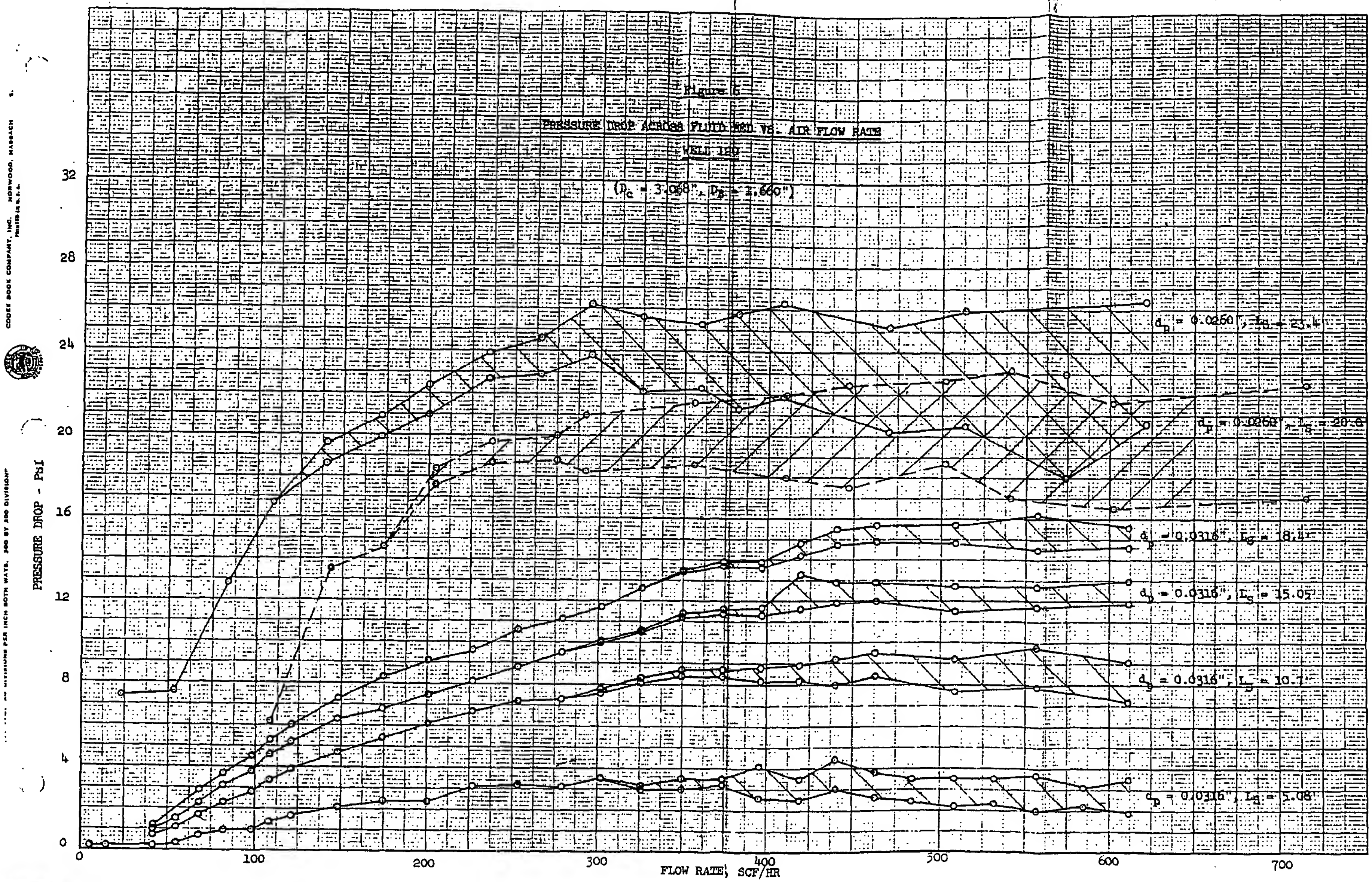


Figure 7

PRESSURE DROP ACROSS FLUID BED

VS. AIR FLOW RATE - WELL 122

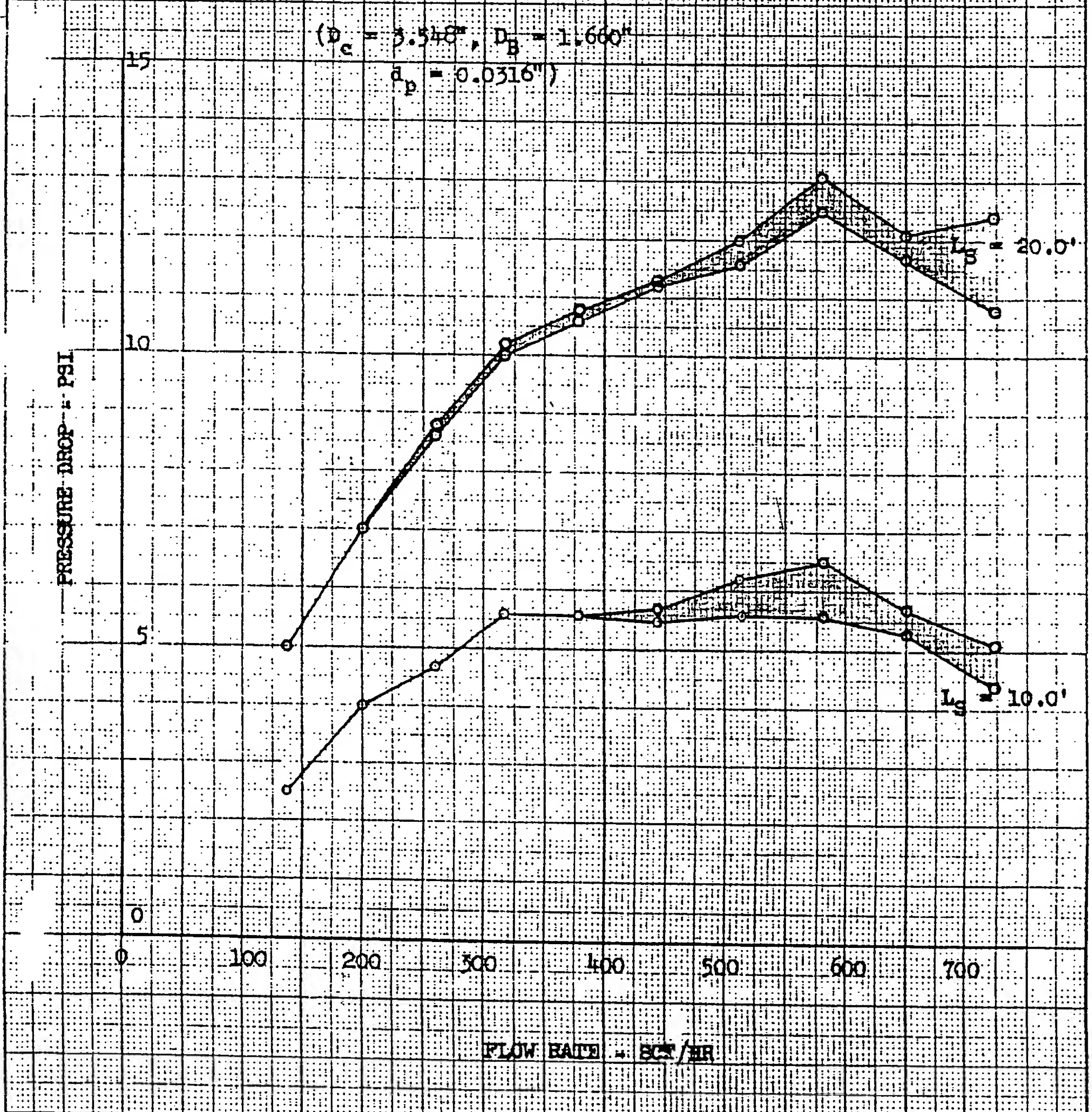


Figure 8

AVERAGE PRESSURE DROP ACROSS FLUID BED

VS. AIR FLOW RATE - WELL 124

(D_C = 4.026", D_B = 1.900"
d_p = 0.0318")

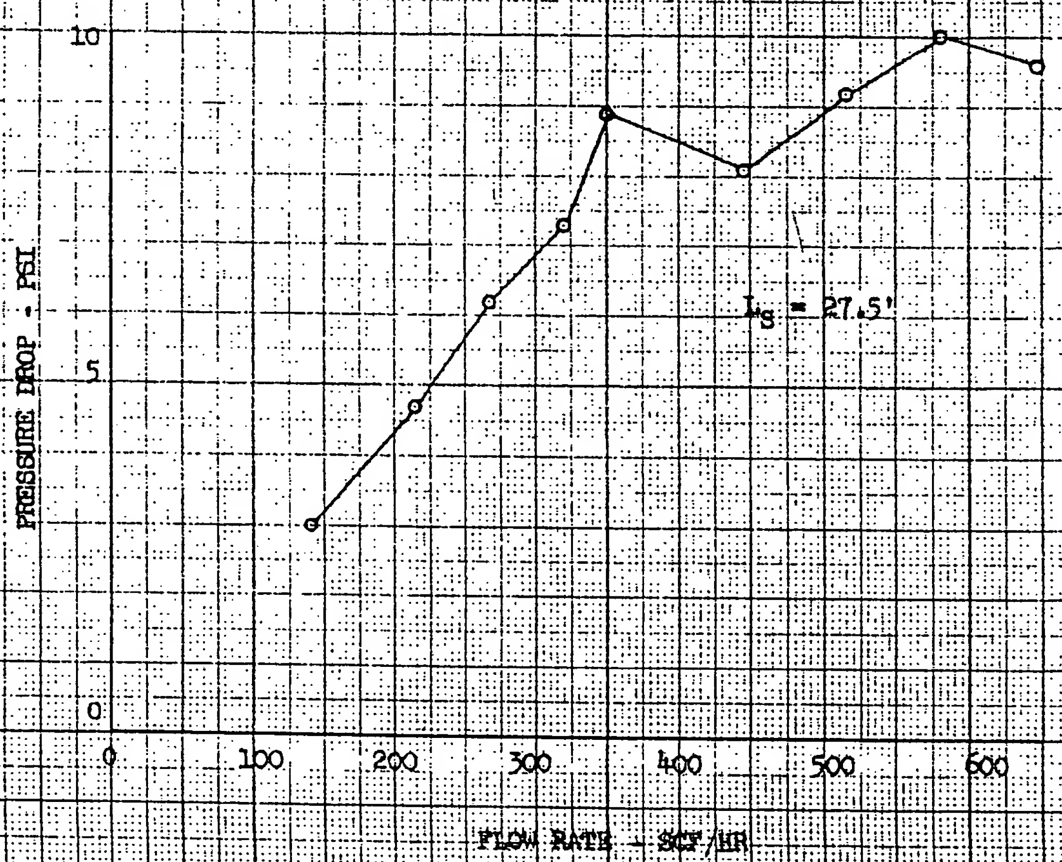
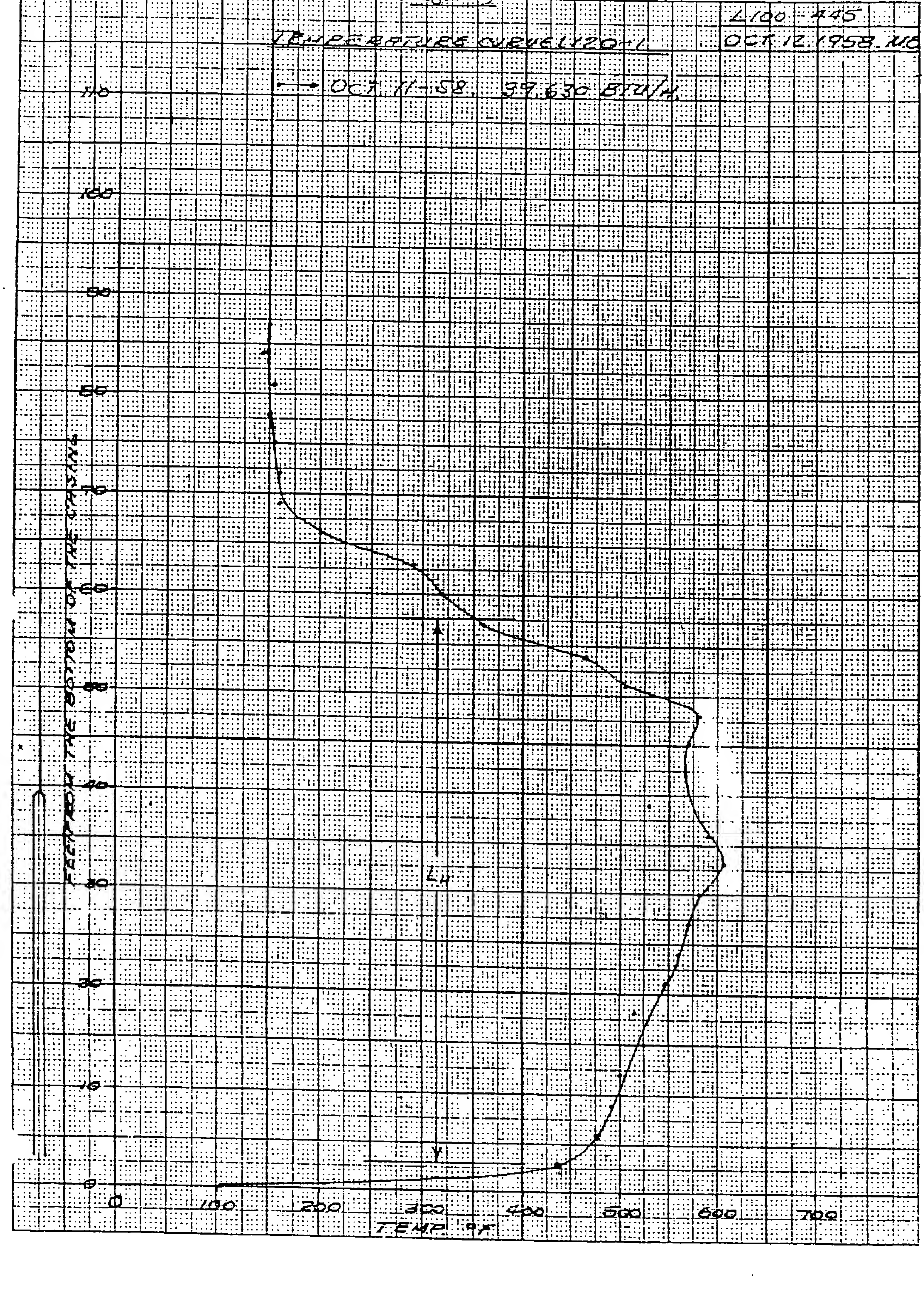


Figure 9


L100-445
OCT 12 1958
OCT 11-58, 39,630 BTU/H
110
100
90
80
70
60
50
40
30
20
10
0
FEET FROM THE BOTTOM OF THE CASING
L4
0
100
200
300
400
500
600
700
TEMP °F

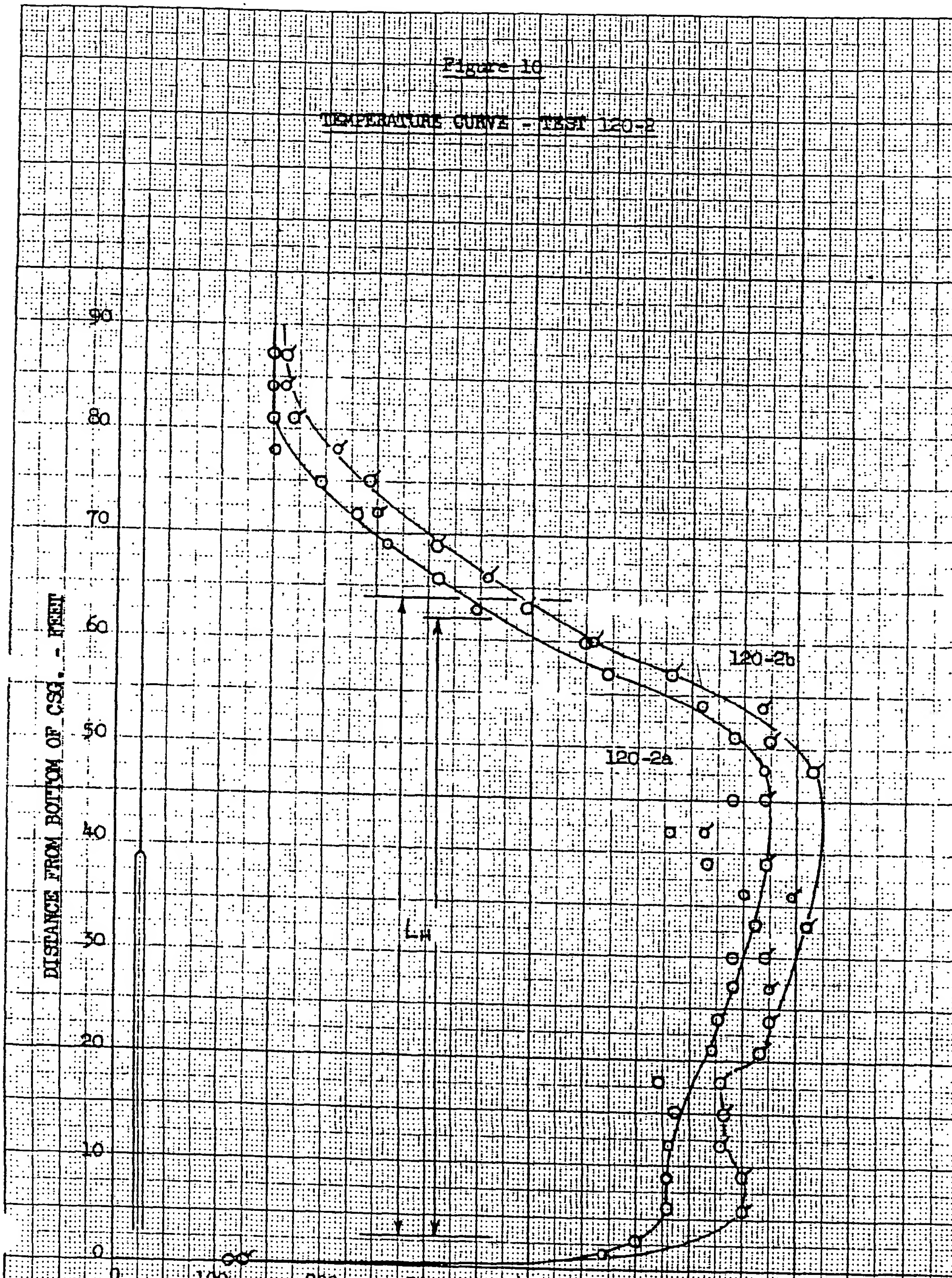


Figure 10
TEMPERATURE CURVE - TEST 120-2
DISTANCE FROM BOTTOM OF CSG. - FEET
TEMPERATURE - °F.
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
120-2b
120-2a
L_H

Figure 11

TEMPERATURE CURVE TEST 120-3

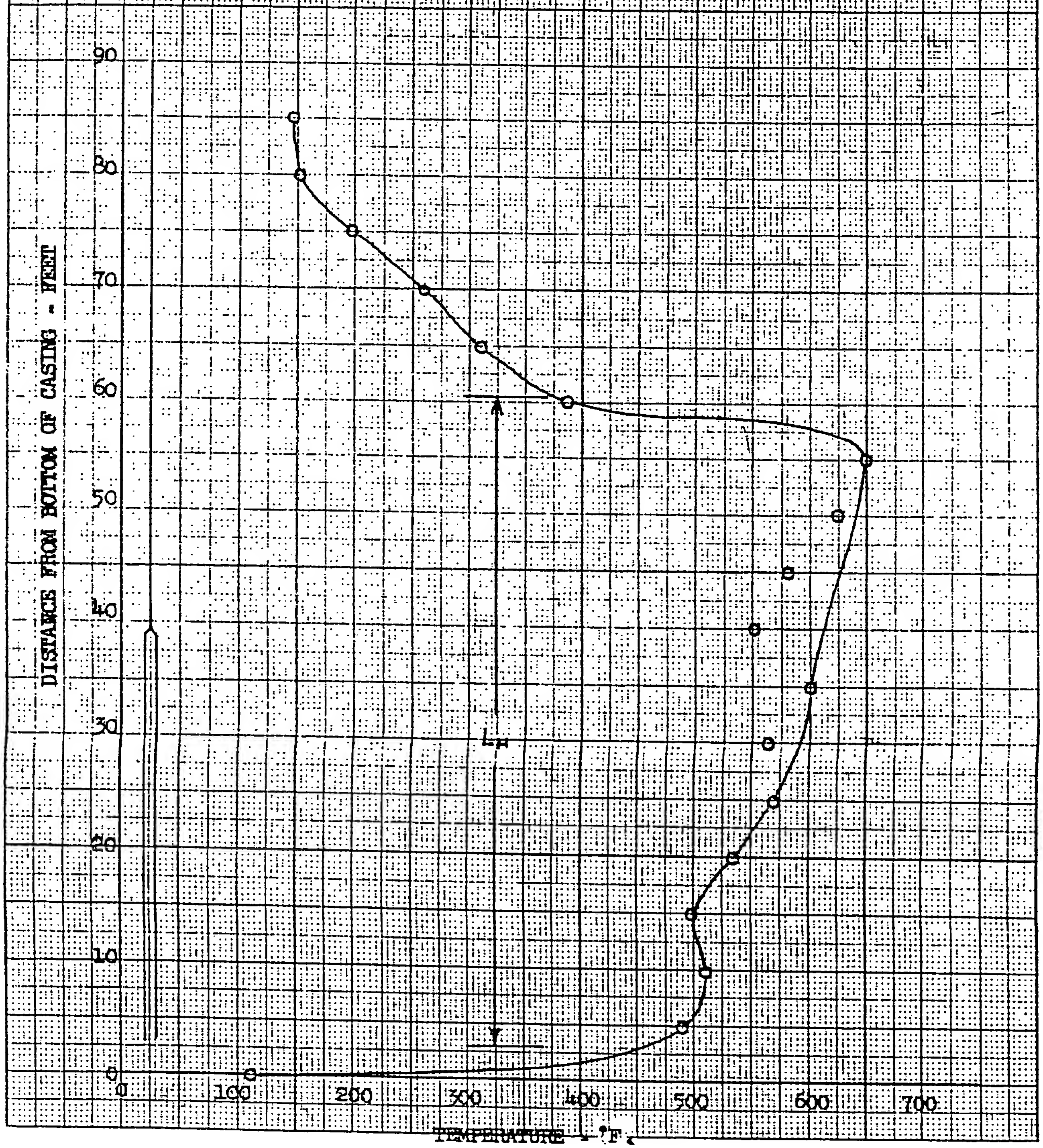


Figure 12

TEMPERATURE CURVE

TEST 120-4

Figure 13

TEMPERATURE CURVE

TEST 121-1

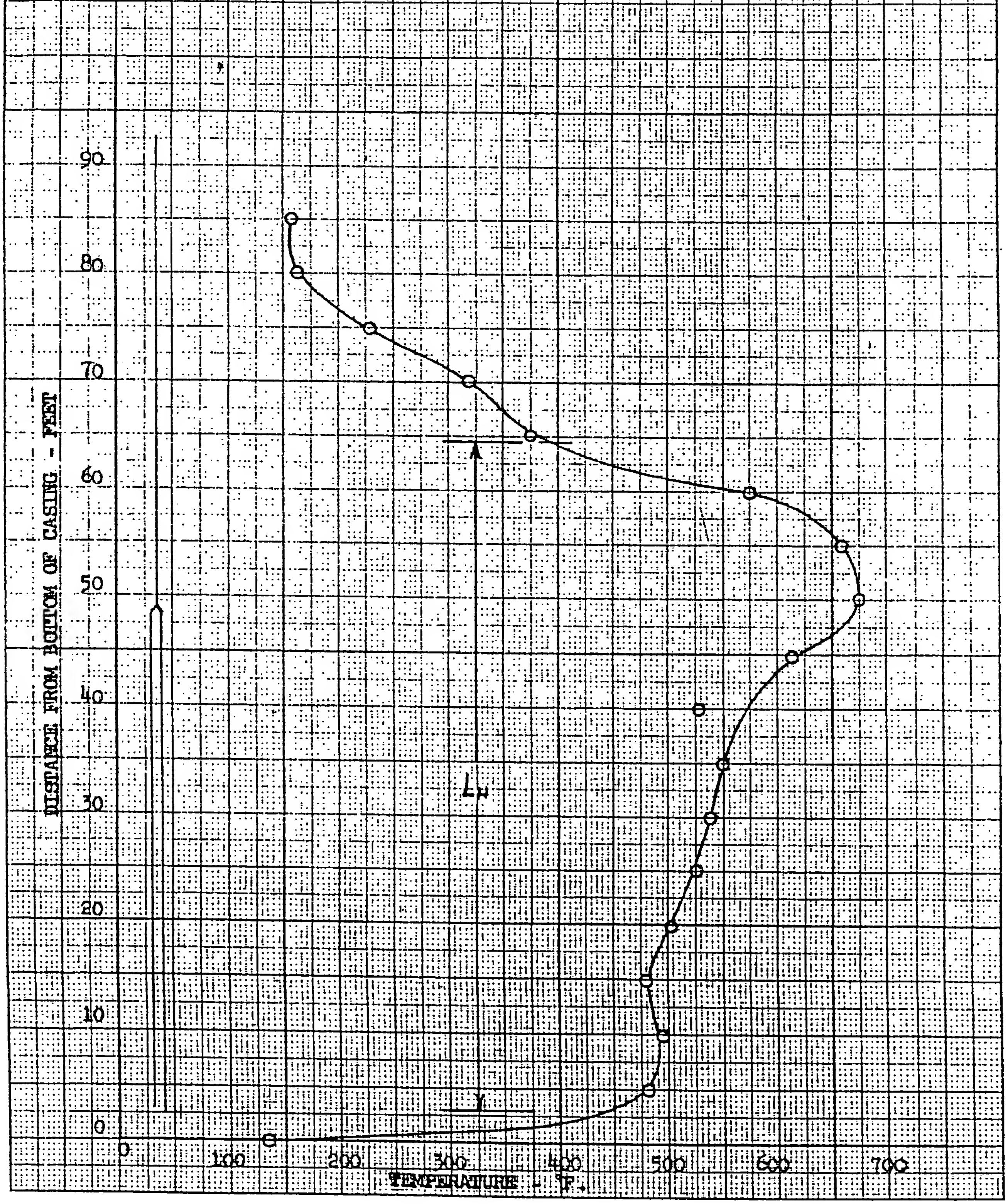


Figure 14

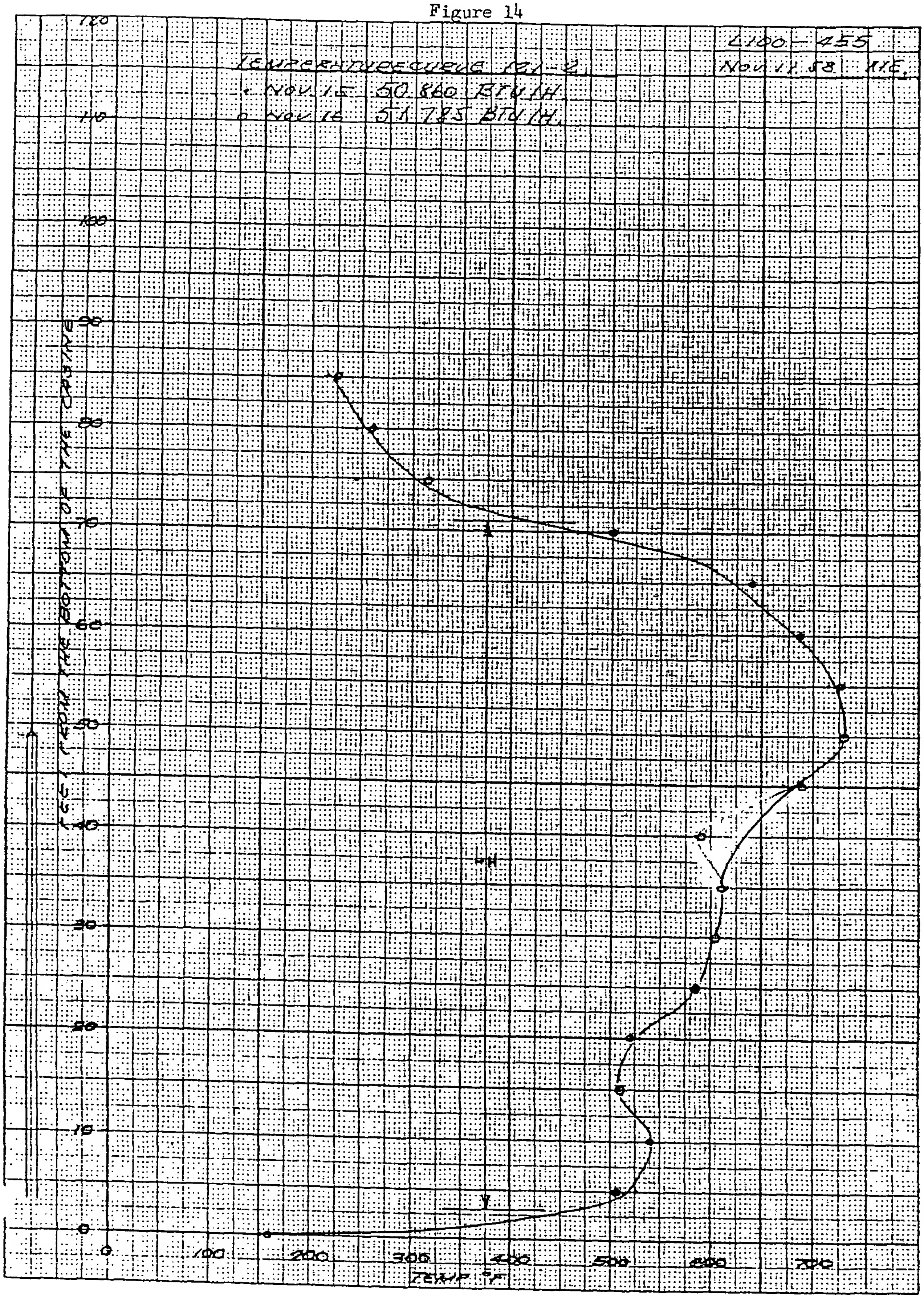

L100-455
Nov. 11, 58
Nov. 15 50 860 BTU/H.
Nov. 16 51 725 BTU/H.
120
110
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
TEMP °F

Figure 15

TEMPERATURE CURVE

TEST 121-3

Figure 16

TEMPERATURE CURVE

TEST 121.4

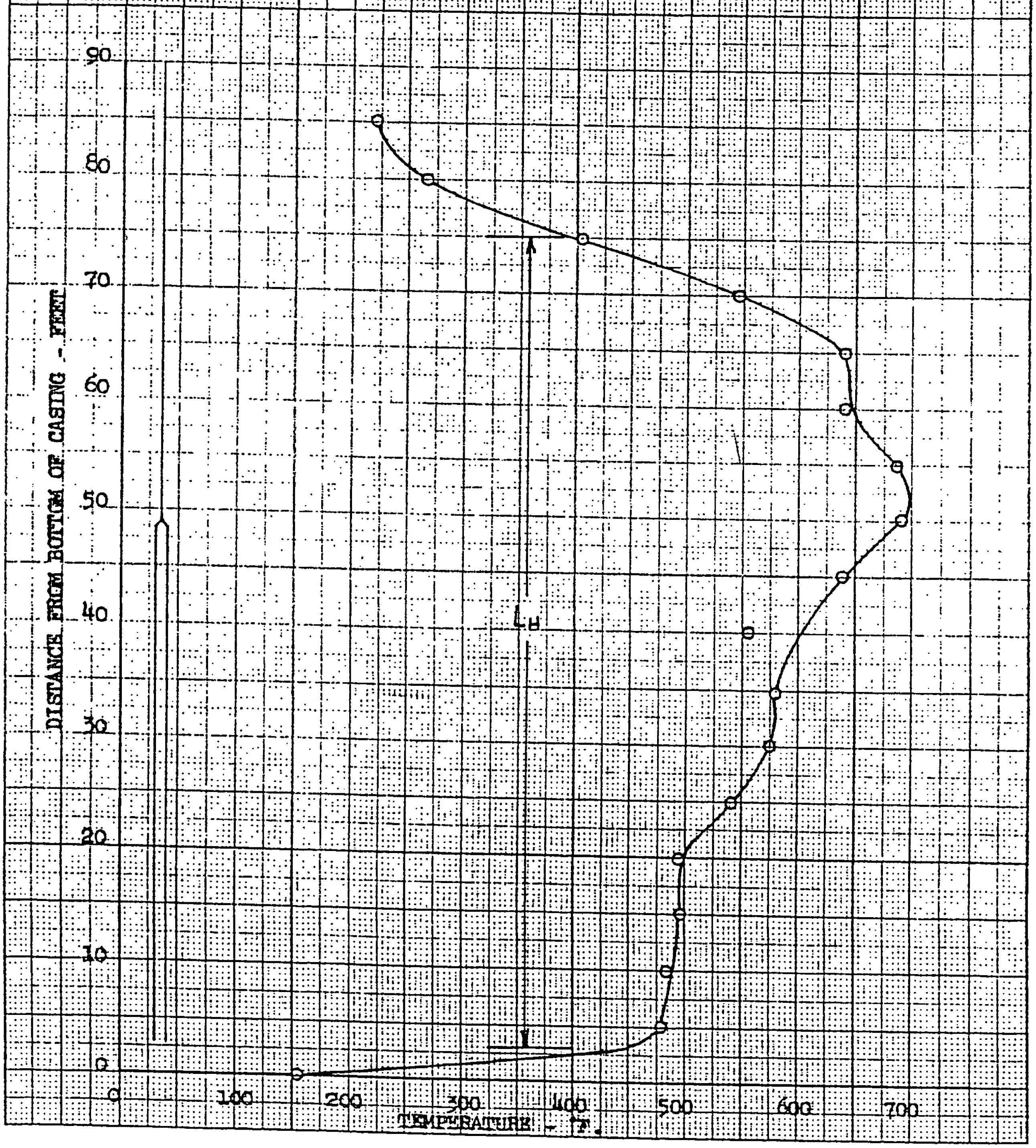
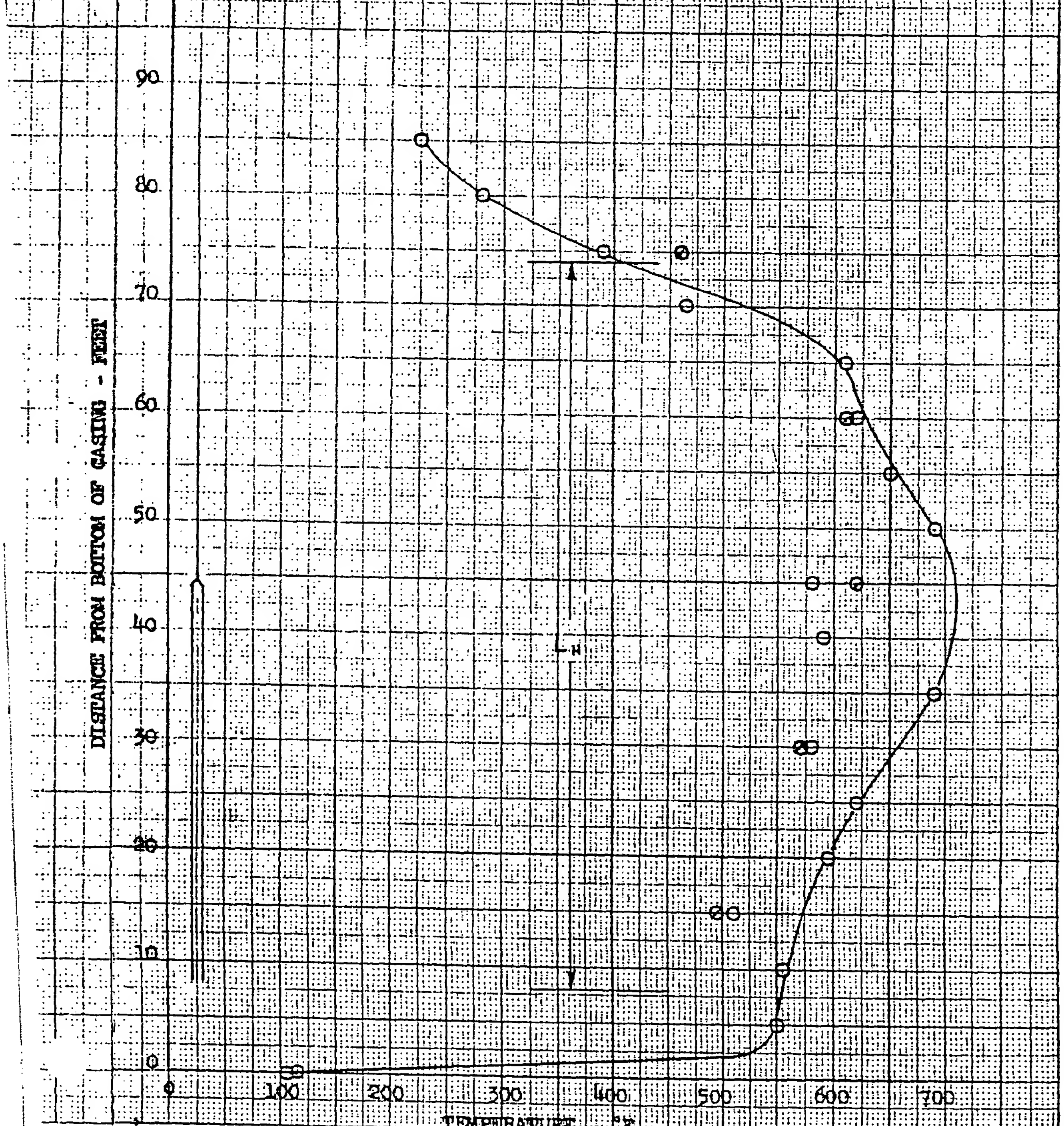


Figure 17

TEMPERATURE CURVE

TEST 120-4B



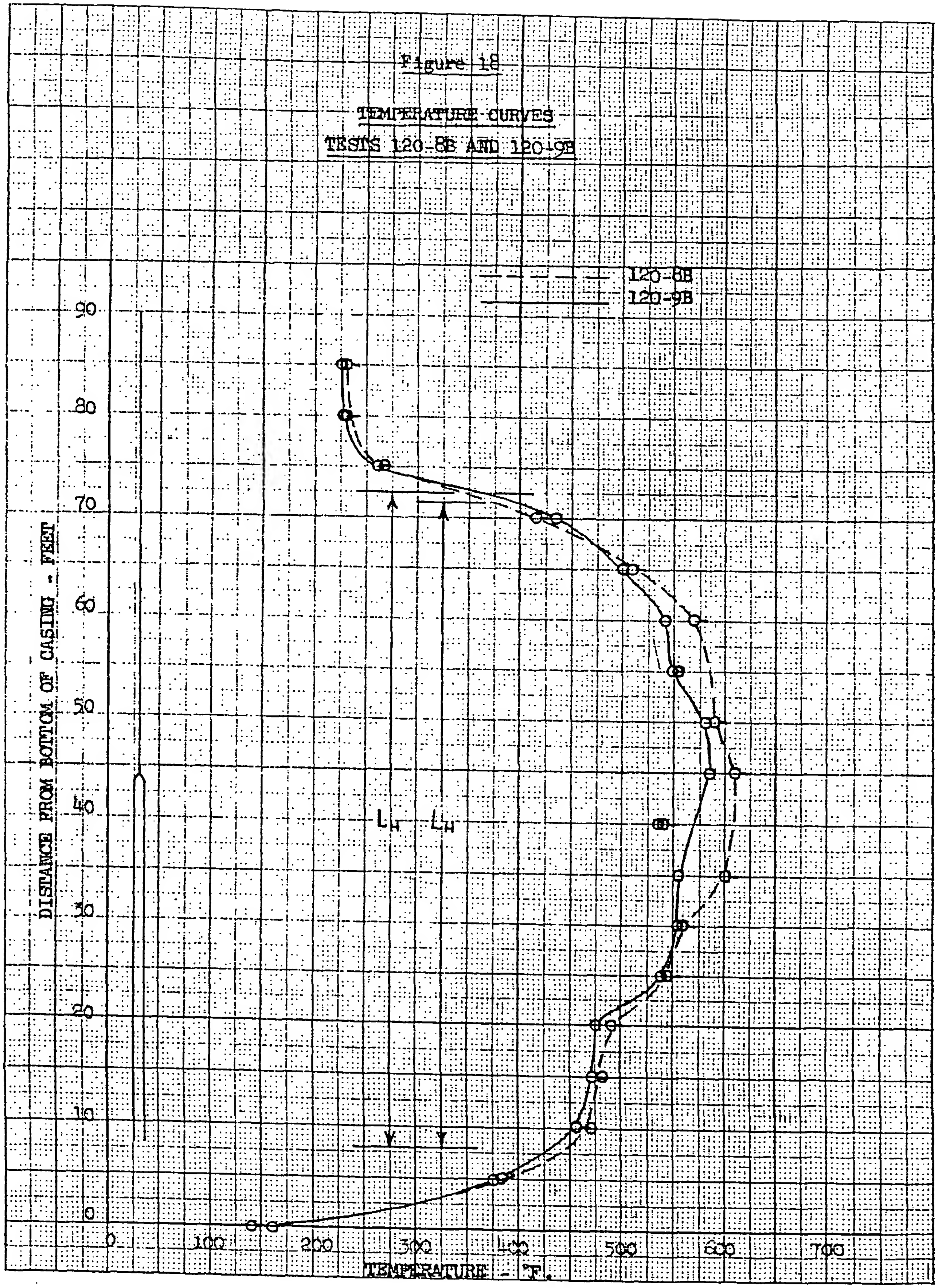


Figure 18
TEMPERATURE CURVES
TESTS 120-8B AND 120-9B
120-8B
120-9B
DISTANCE FROM BOTTOM OF CASING - FEET
TEMPERATURE - °F.
L_H
L_H
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700

Figure 20

TEMPERATURE CURVES

TEST 121-2B

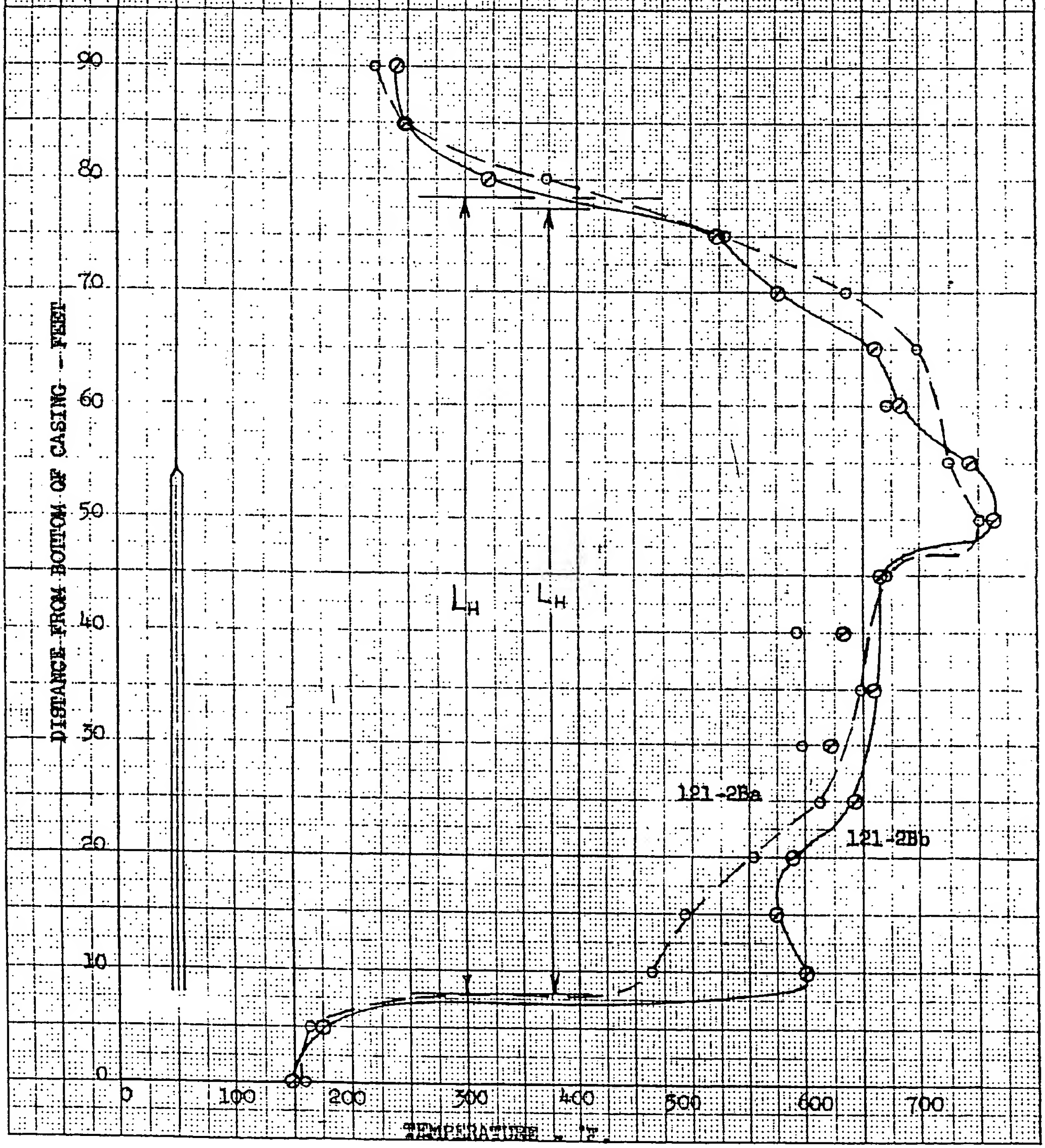


Figure 21

TEMPERATURE CURVE

TEST 121-3B

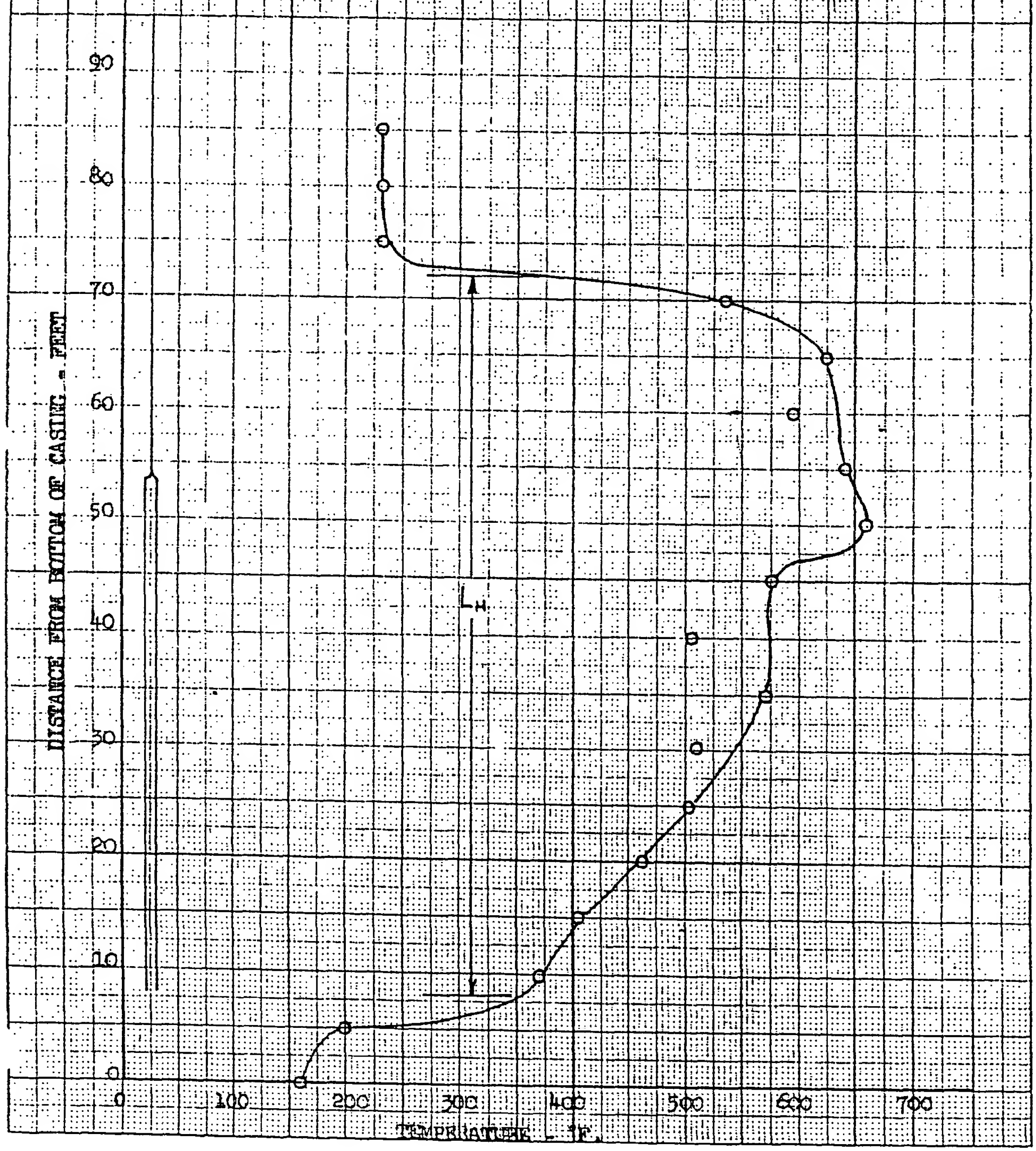
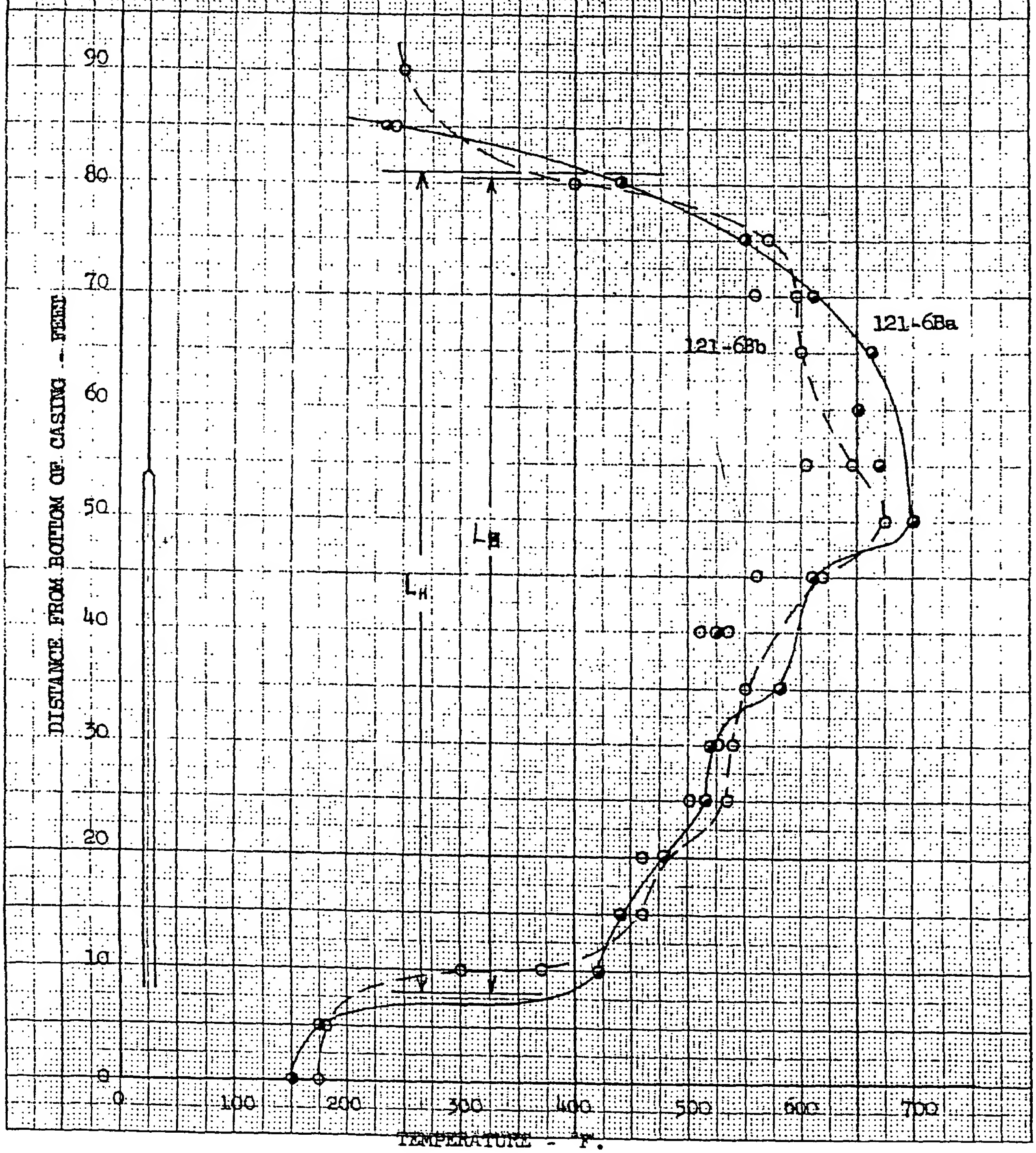


Figure 22

TEMPERATURE CURVE

TEST 121-6B



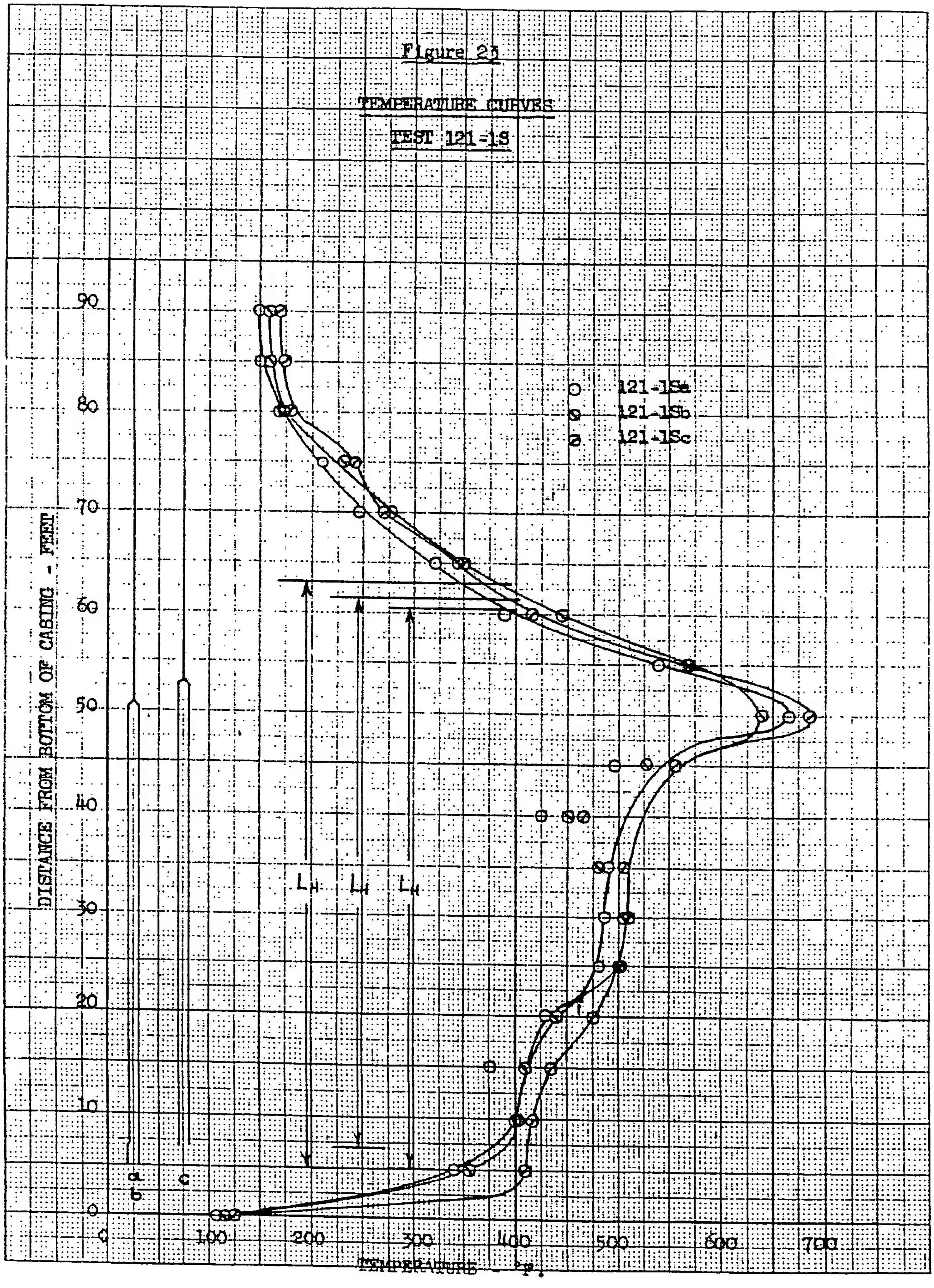


Figure 23
TEMPERATURE CURVES
TEST 121-1S
121-1Sa
121-1Sb
121-1Sc
DISTANCE FROM BOTTOM OF CASING - FEET
TEMPERATURE - °F.
0
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
a
b
c
L_H
L_H
L_H

Figure 24

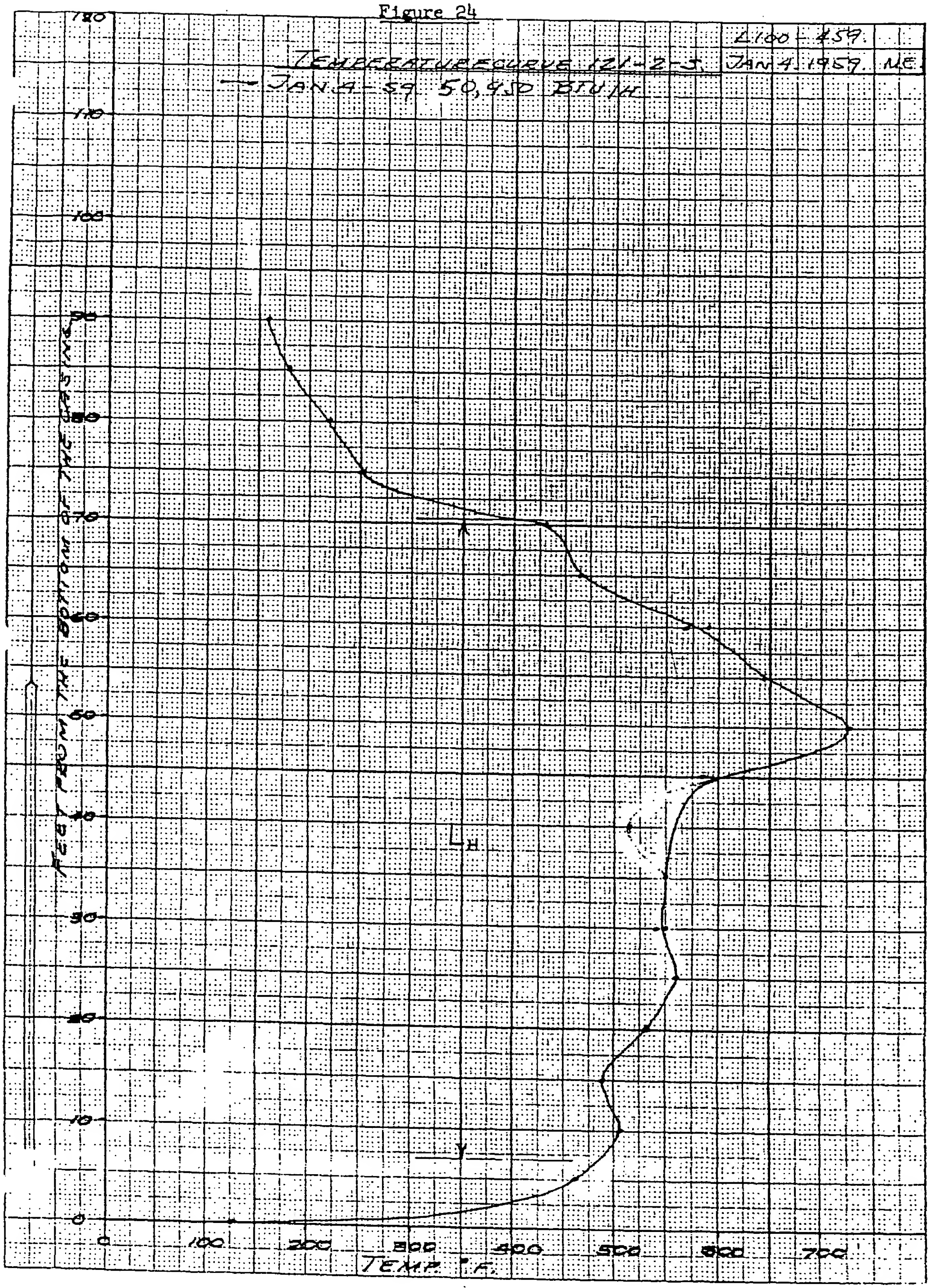
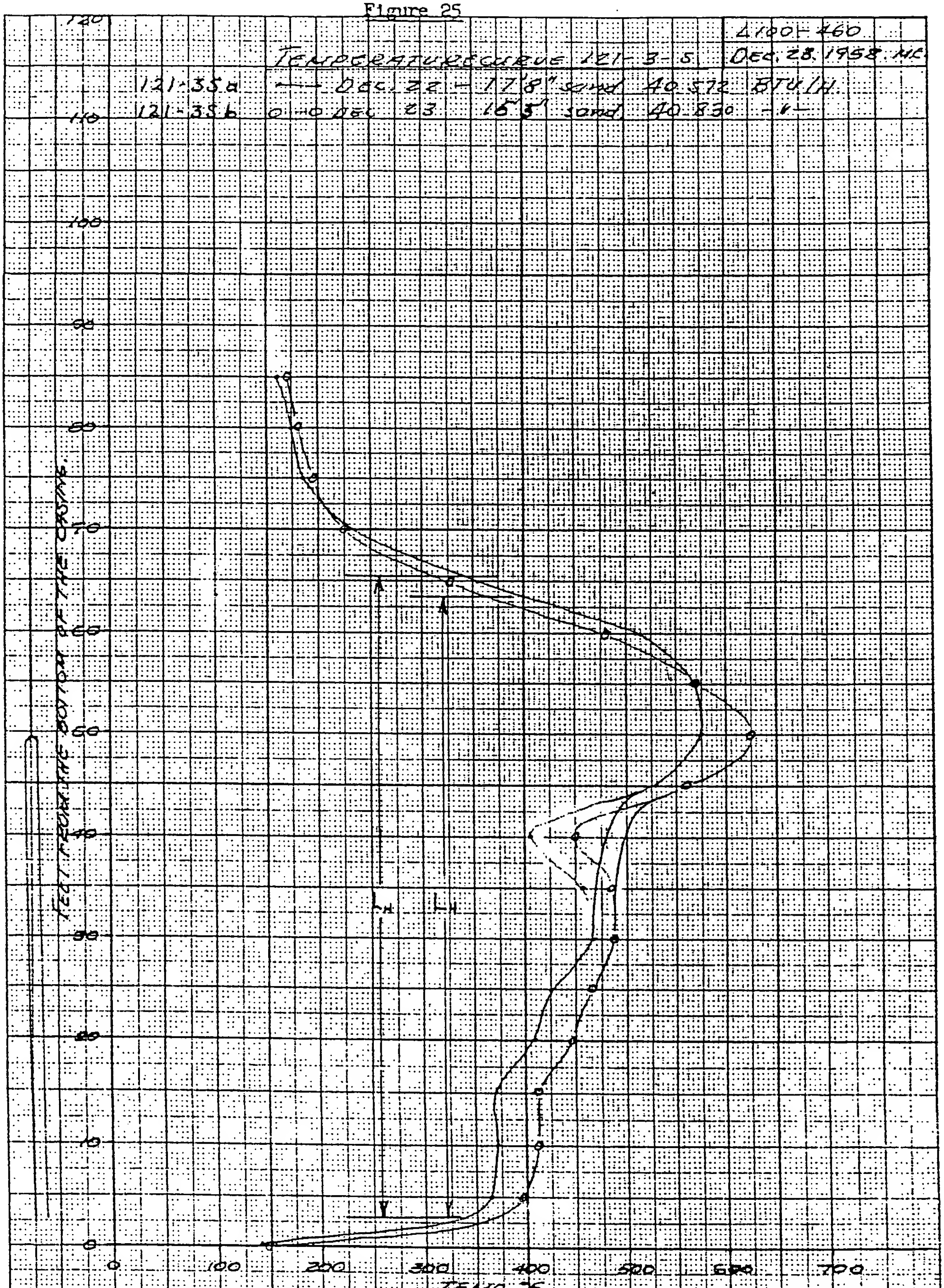
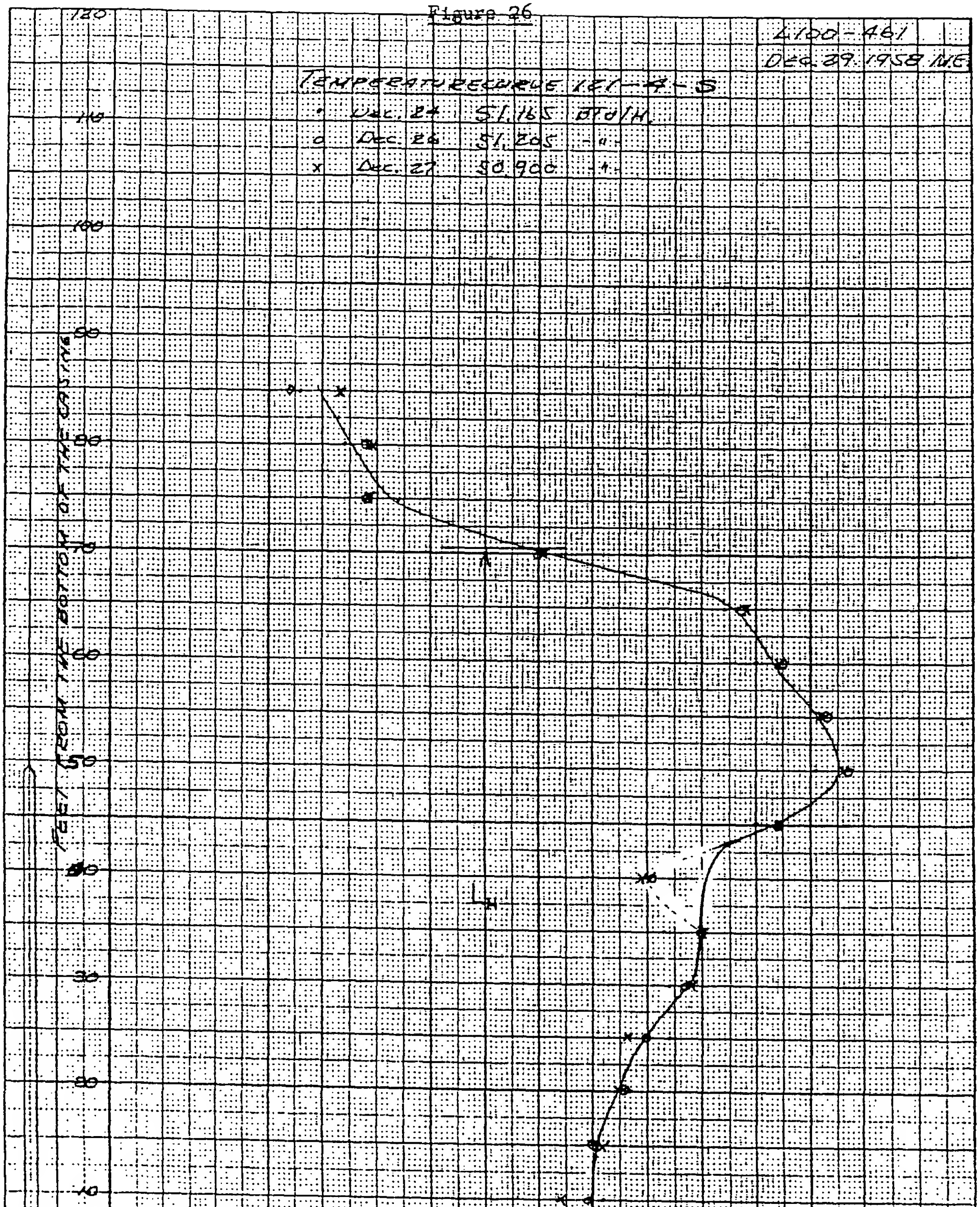

L100-459
TEMPERATURE CURVE 121-2-3 JAN 4 1959 NE
JAN 4-59 50,450 BTU/H
FEET FROM THE BOTTOM OF THE CASING
TEMP. °F.
120
110
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
H

Figure 25



4100-460
TEMPERATURE CURVE 121-3-5
DEC. 28. 1958
121-35a —— DEC 22 – 17'8" sand 40 572 BTU/H.
121-35b o-o DEC 23 16'5" sand 40 830 –"–
FEET FROM THE BOTTOM OF THE CASING
TEMP °C
0
100
200
300
400
500
600
700
10
20
30
40
50
60
70
80
90
100
110
120

Figure 26



4100-461
Dec. 29. 1958 M.E.
TEMPERATURE CURVE 121-4-S
• Dec. 24 51.165 BTU/H.
o Dec. 26 51.205 -"-
x Dec. 27 50.900 -"-
FEET FROM THE BOTTOM OF THE CASING
TEMP. °F
0
10
20
30
40
50
60
70
80
90
100
110
120
0
100
200
300
400
500
600
700

Figure 27

TEMPERATURE CURVES

TEST 121-3BS

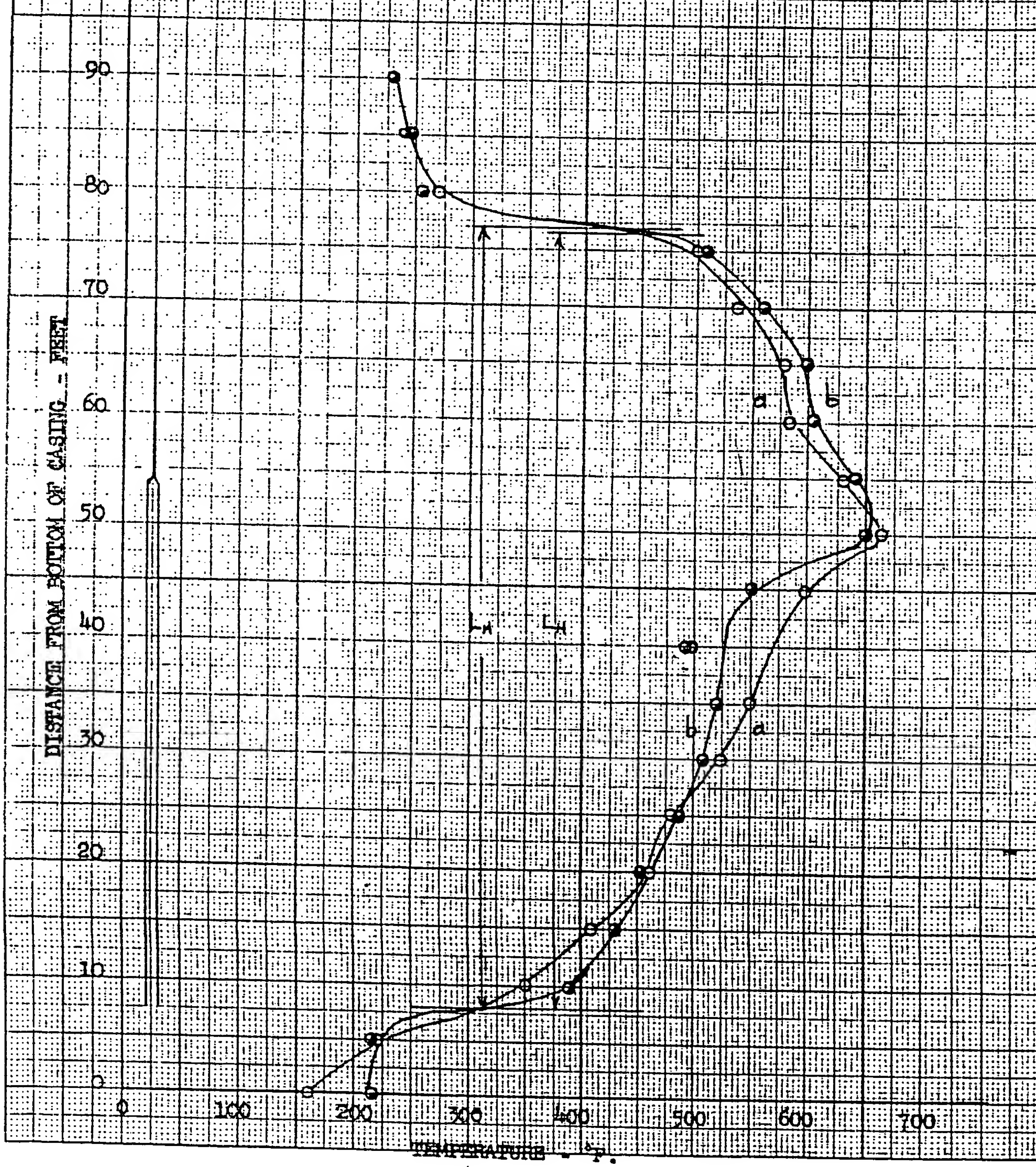
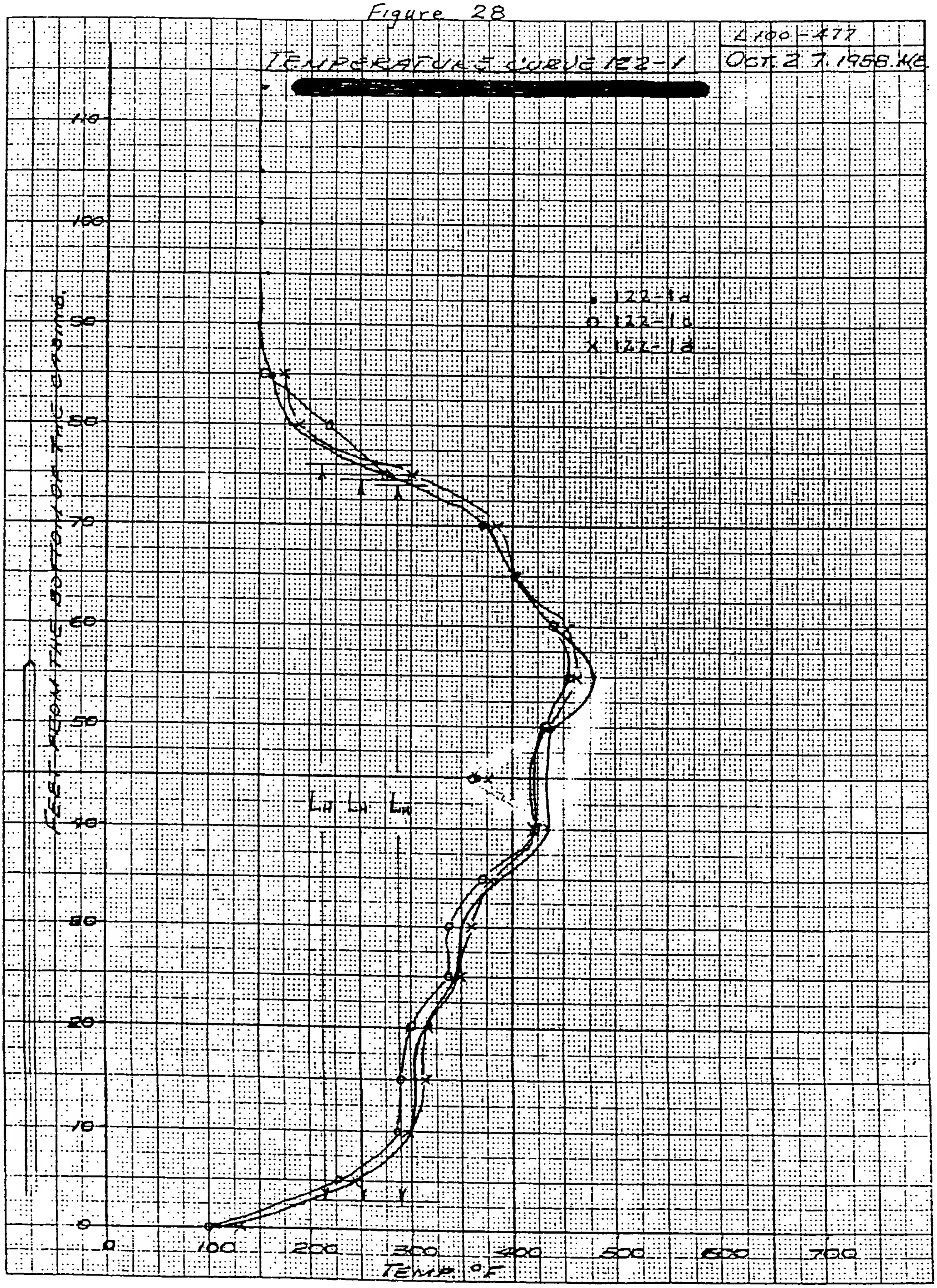


Figure 28


L100-477
Oct. 27, 1958 KE
TEMPERATURE CURVE 122-1
[redacted]
• 122-1a
o 122-1b
x 122-1c
FEET FROM THE BOTTOM OF THE CASING
110
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
TEMP °F
LH LH LH

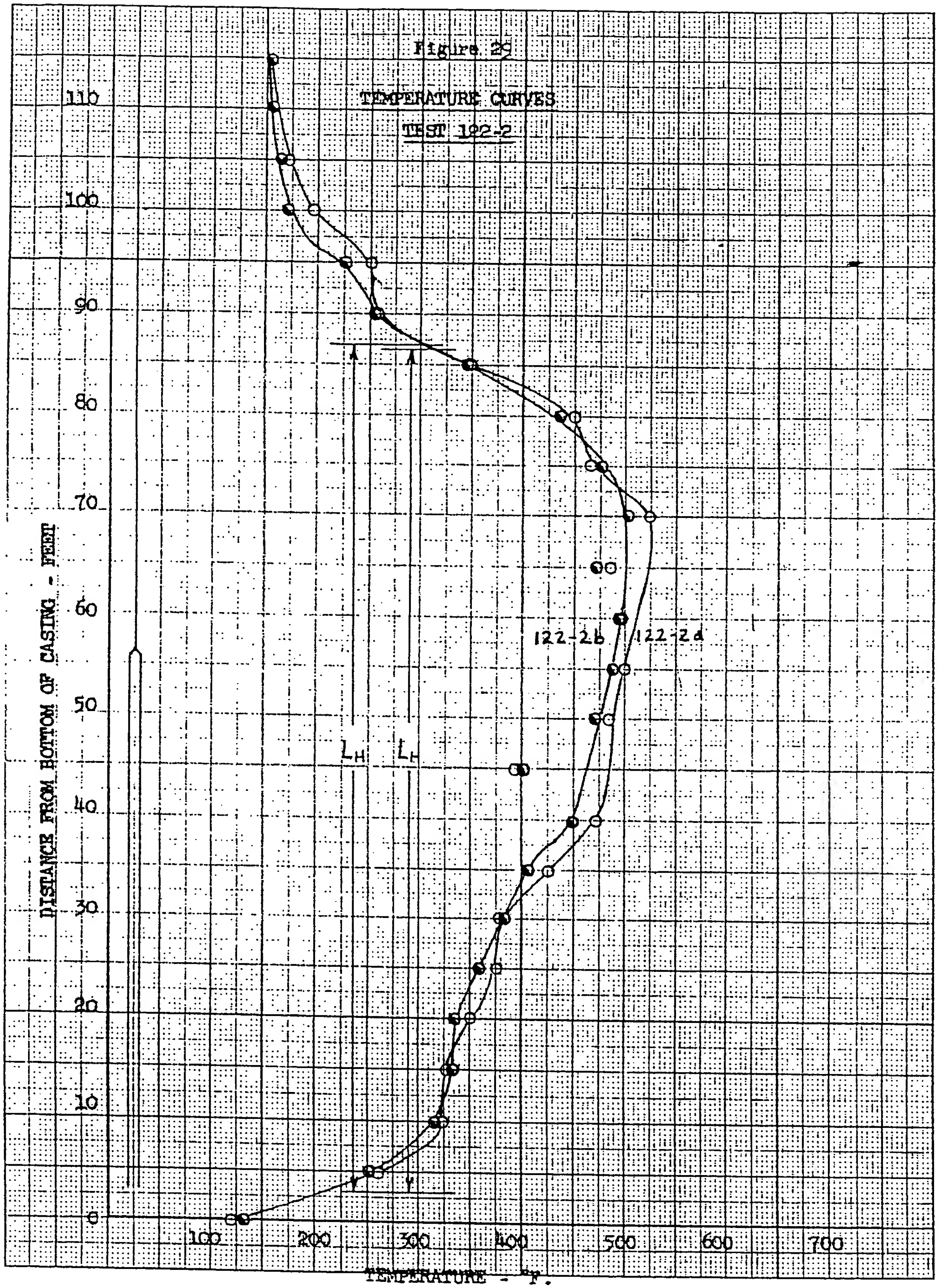


Figure 29
TEMPERATURE CURVES
TEST 122-2
110
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
DISTANCE FROM BOTTOM OF CASING - FEET
TEMPERATURE - °F.
L_H
L_H
122-2b
122-2d

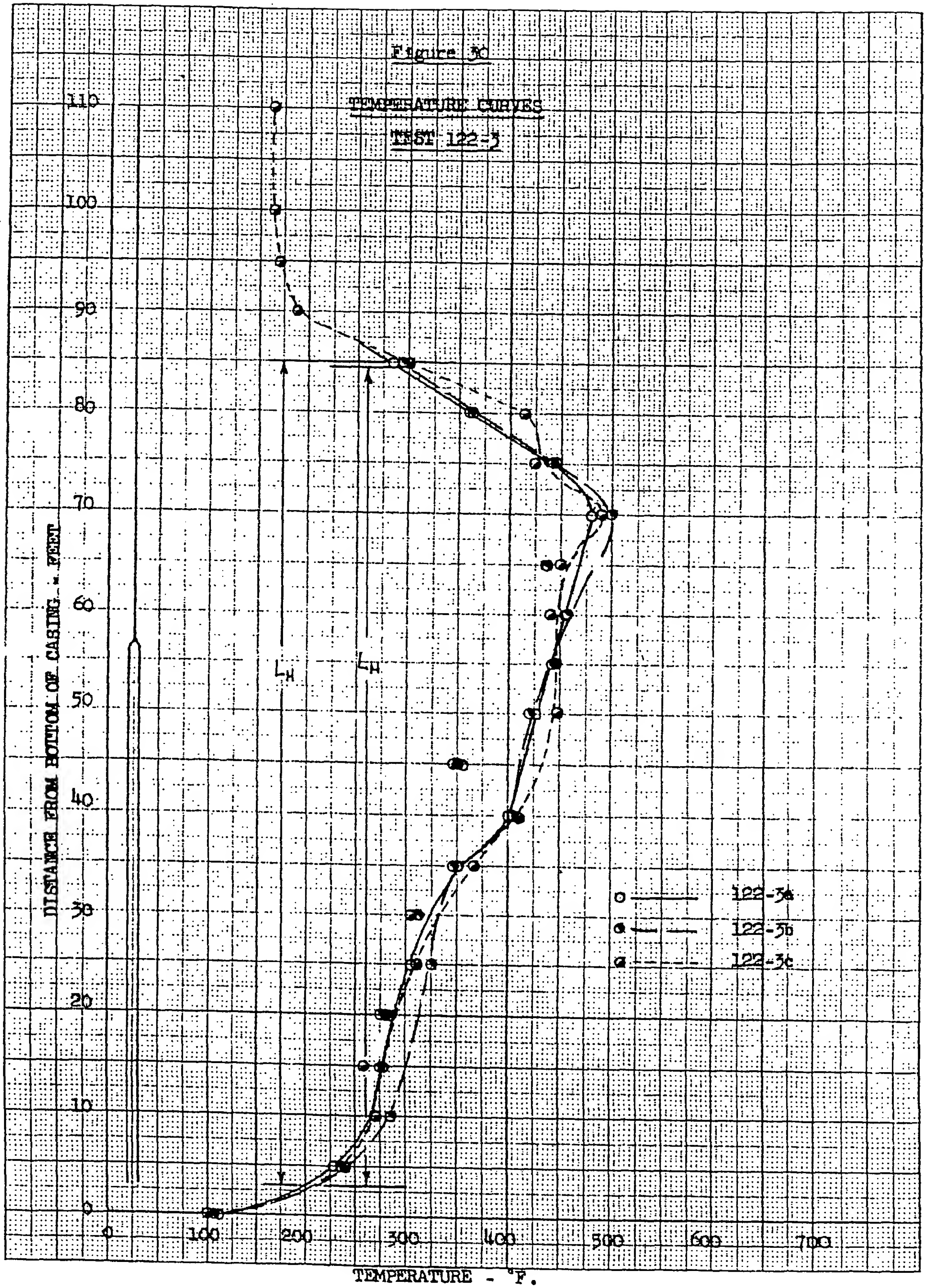
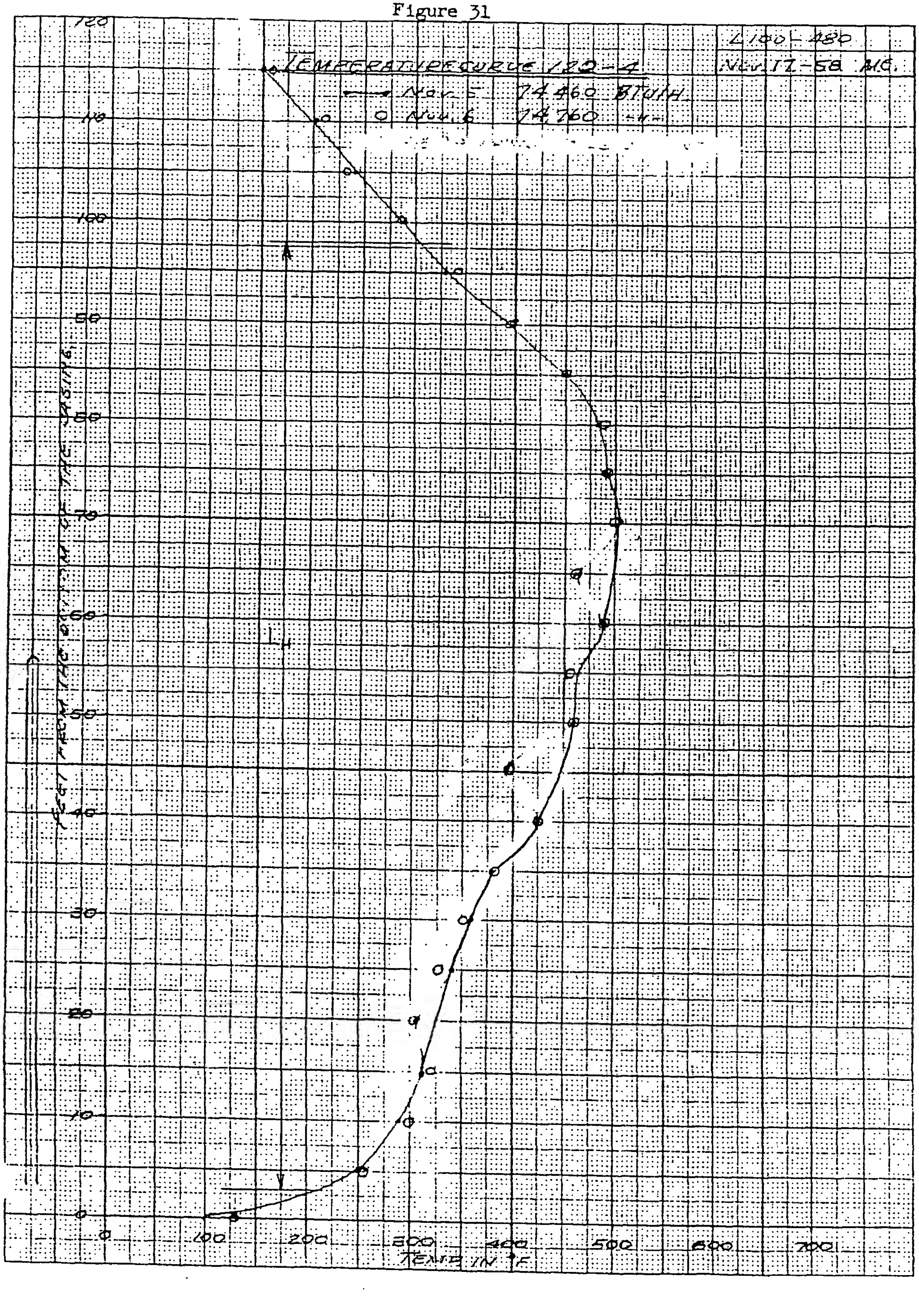


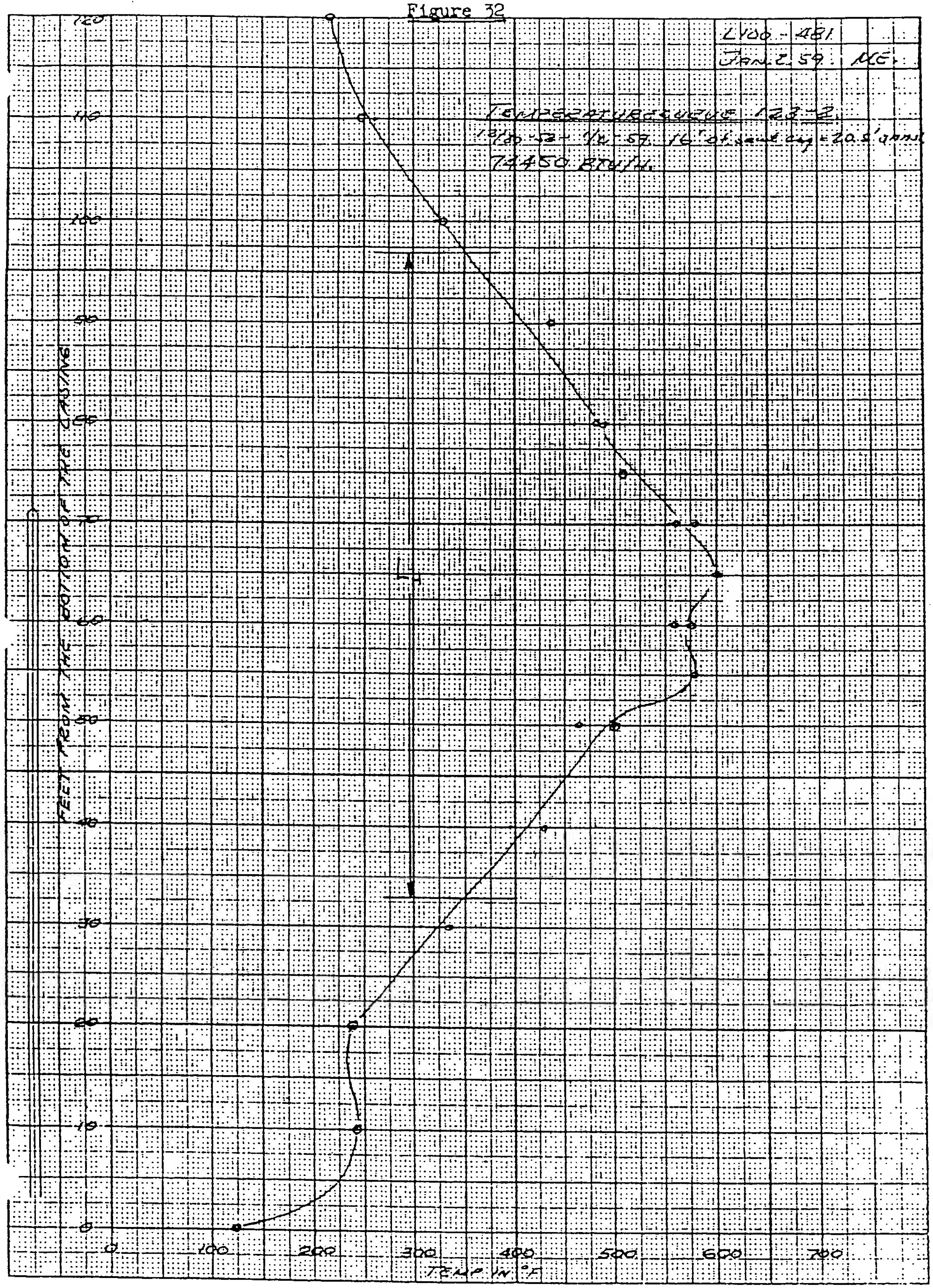
Figure 30
TEMPERATURE CURVES
TEST 122-3
DISTANCE FROM BOTTOM OF CASING - FEET
TEMPERATURE - °F.
L_H
L_H
122-3a
122-3b
122-3c
0
100
200
300
400
500
600
700
0
10
20
30
40
50
60
70
80
90
100
110

Figure 31



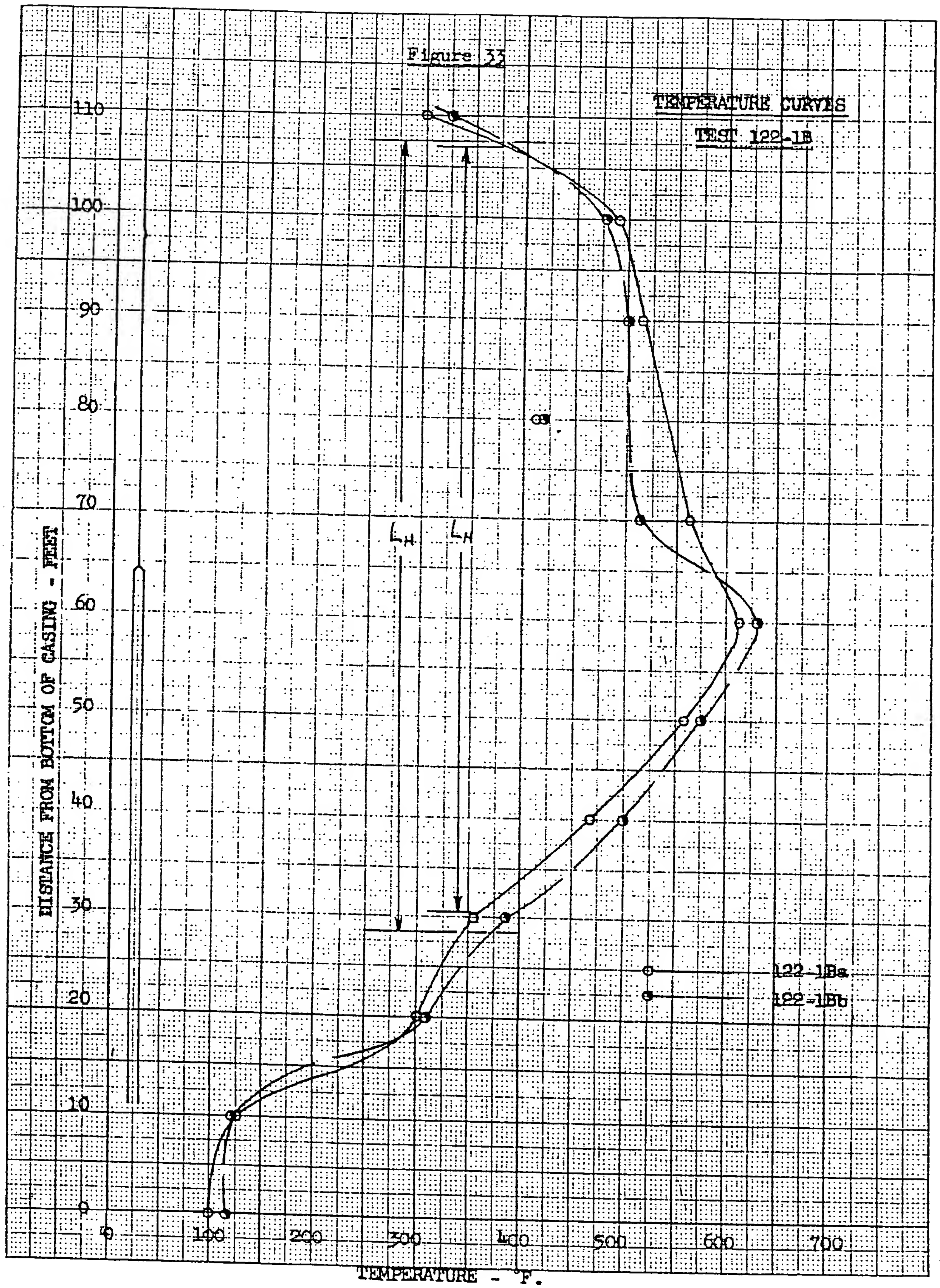
TEMPERATURE CURVE 122-4
Nov 5 74460 BTU/H.
Nov 6 74760
L100-480
Nov 17-58
120
110
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
TEMP IN °F

Figure 32



LVOO - 481
JAN. 2. 59. MC.
TEMPERATURE CURVE 123-2
74450 BTU/H.
FEET FROM THE BOTTOM OF THE CASING
120
110
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
TEMP IN °F

Figure 33


TEMPERATURE CURVES
TEST 122-1B
DISTANCE FROM BOTTOM OF CASING - FEET
110
100
90
80
70
60
50
40
30
20
10
0
L_H
L_H
122-1Ba
122-1Bb
0
100
200
300
400
500
600
700
TEMPERATURE - °F.

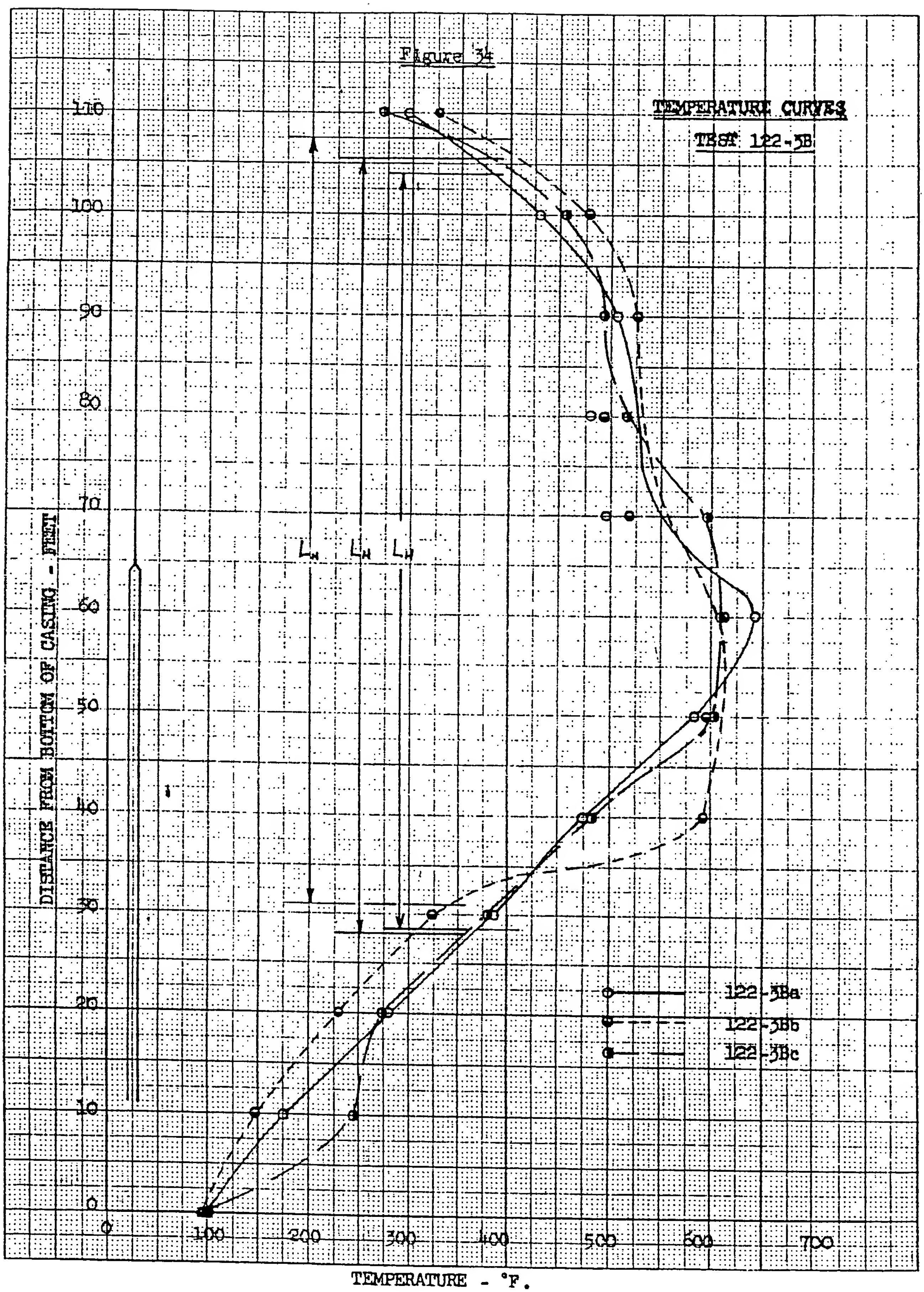
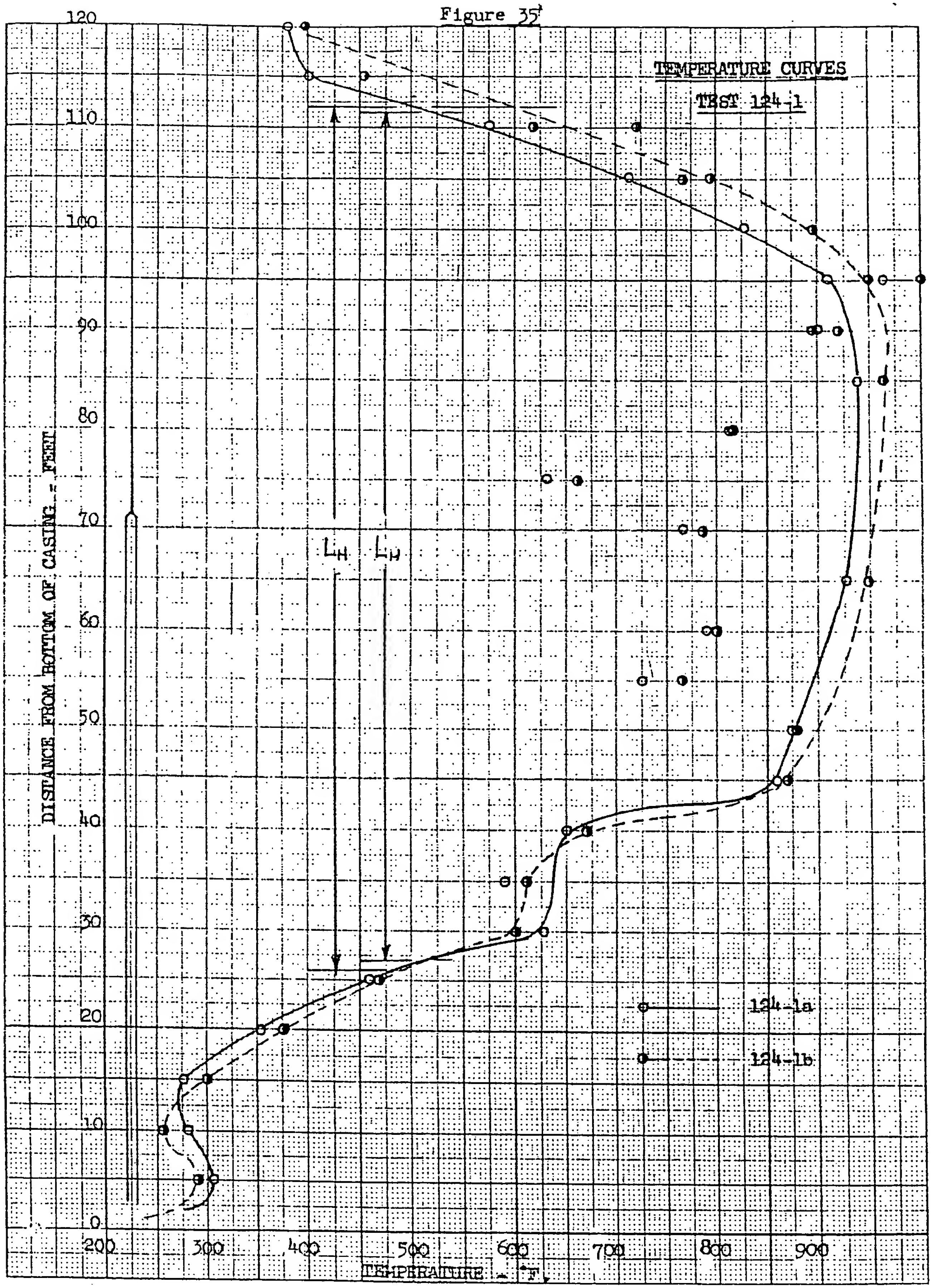


Figure 34
TEMPERATURE CURVES
TEST 122-3B
DISTANCE FROM BOTTOM OF CASING - FEET
TEMPERATURE - °F.
0
10
20
30
40
50
60
70
80
90
100
110
0
100
200
300
400
500
600
700
L_H
L_H
L_H
122-3Ba
122-3Bb
122-3Bc

Figure 35


TEMPERATURE CURVES
TEST 124-1
DISTANCE FROM BOTTOM OF CASING - FEET
TEMPERATURE - °F
L_H
L_H
124-1a
124-1b
0
10
20
30
40
50
60
70
80
90
100
110
120
200
300
400
500
600
700
800
900

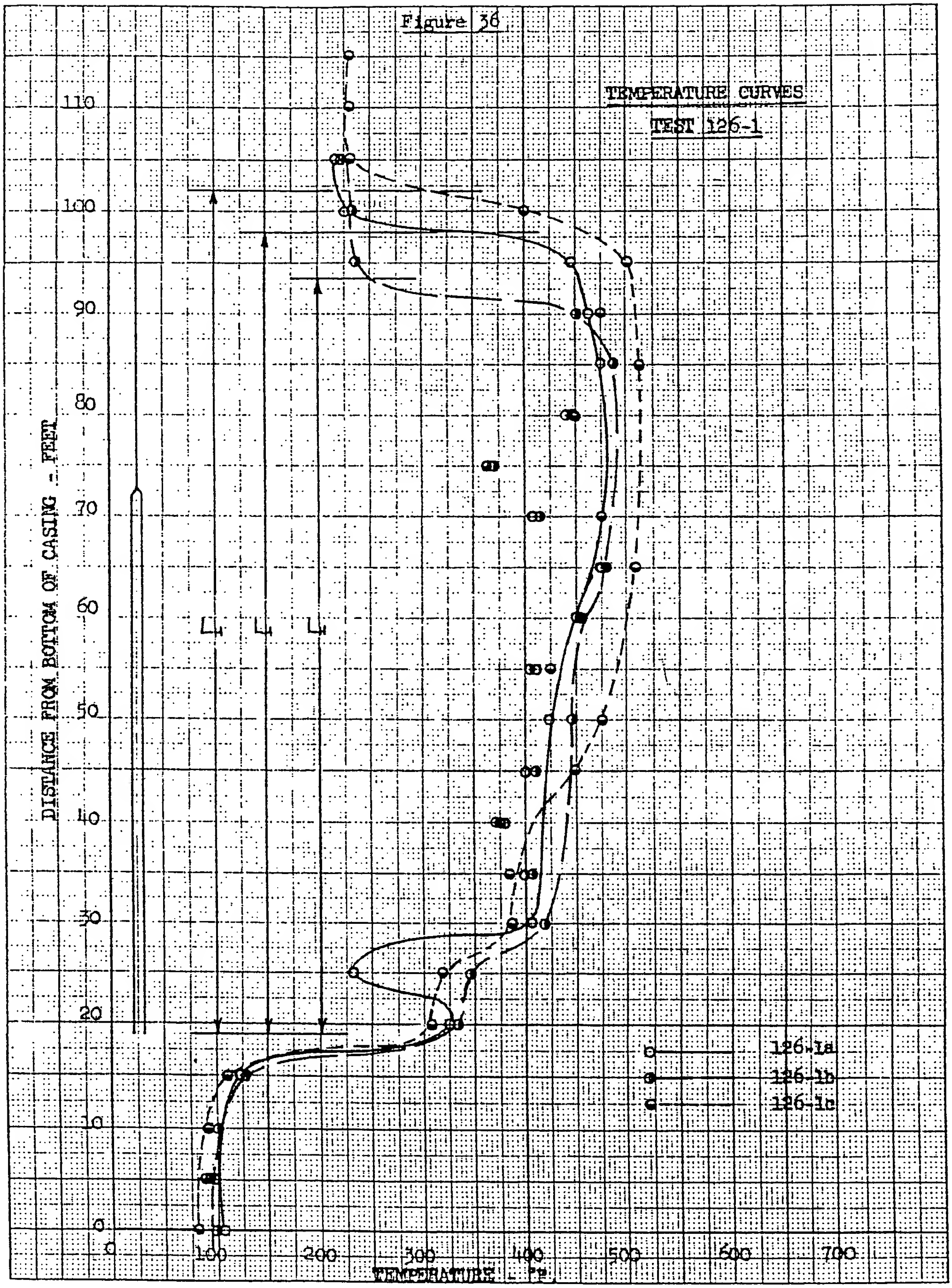


Figure 36
TEMPERATURE CURVES
TEST 126-1
DISTANCE FROM BOTTOM OF CASING - FEET
TEMPERATURE - °F
126-1a
126-1b
126-1c
0
10
20
30
40
50
60
70
80
90
100
110
0
100
200
300
400
500
600
700

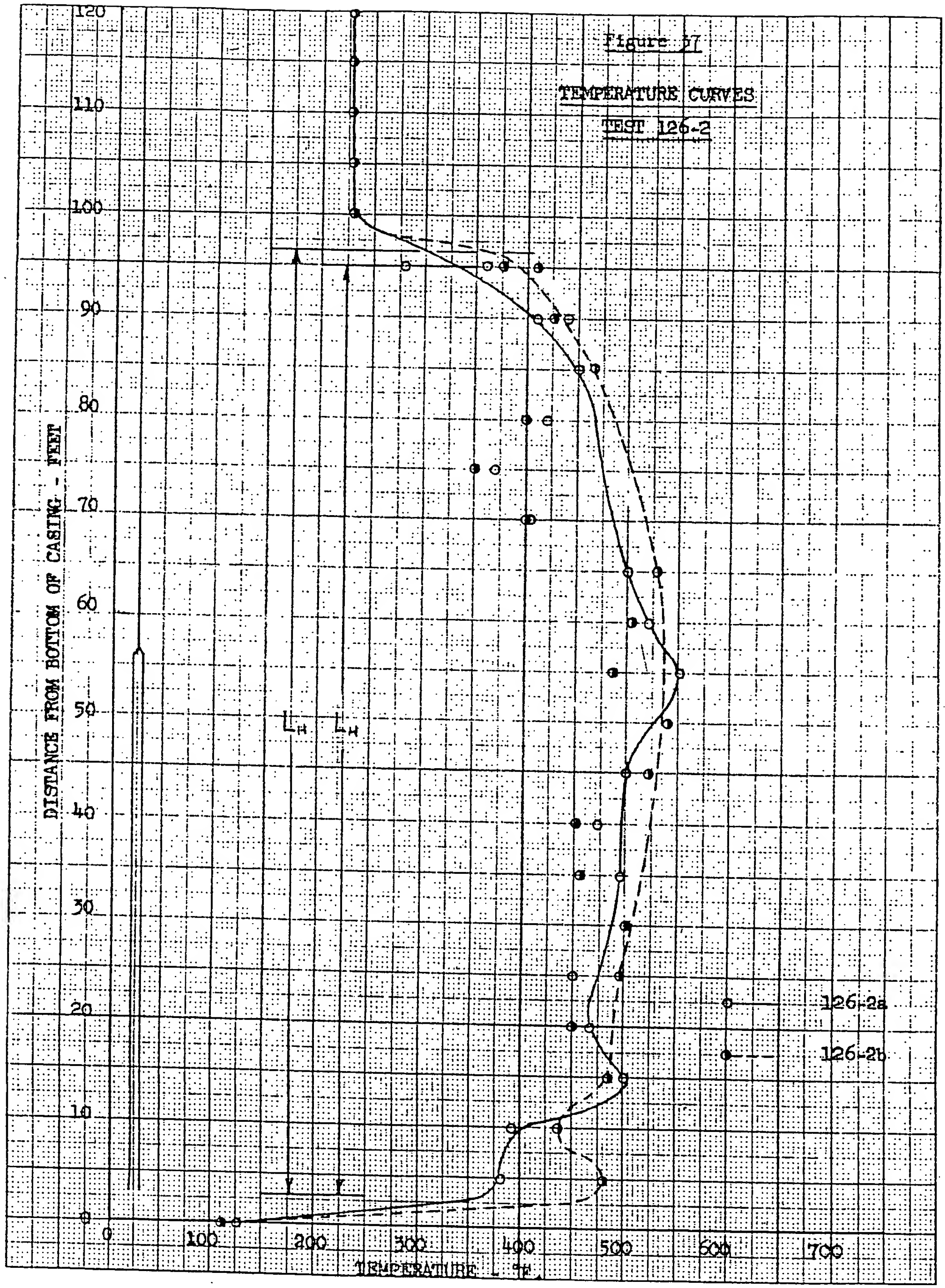


Figure 57
TEMPERATURE CURVES
TEST 126-2
DISTANCE FROM BOTTOM OF CASING - FEET
TEMPERATURE - °F.
120
110
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
126-2a
126-2b

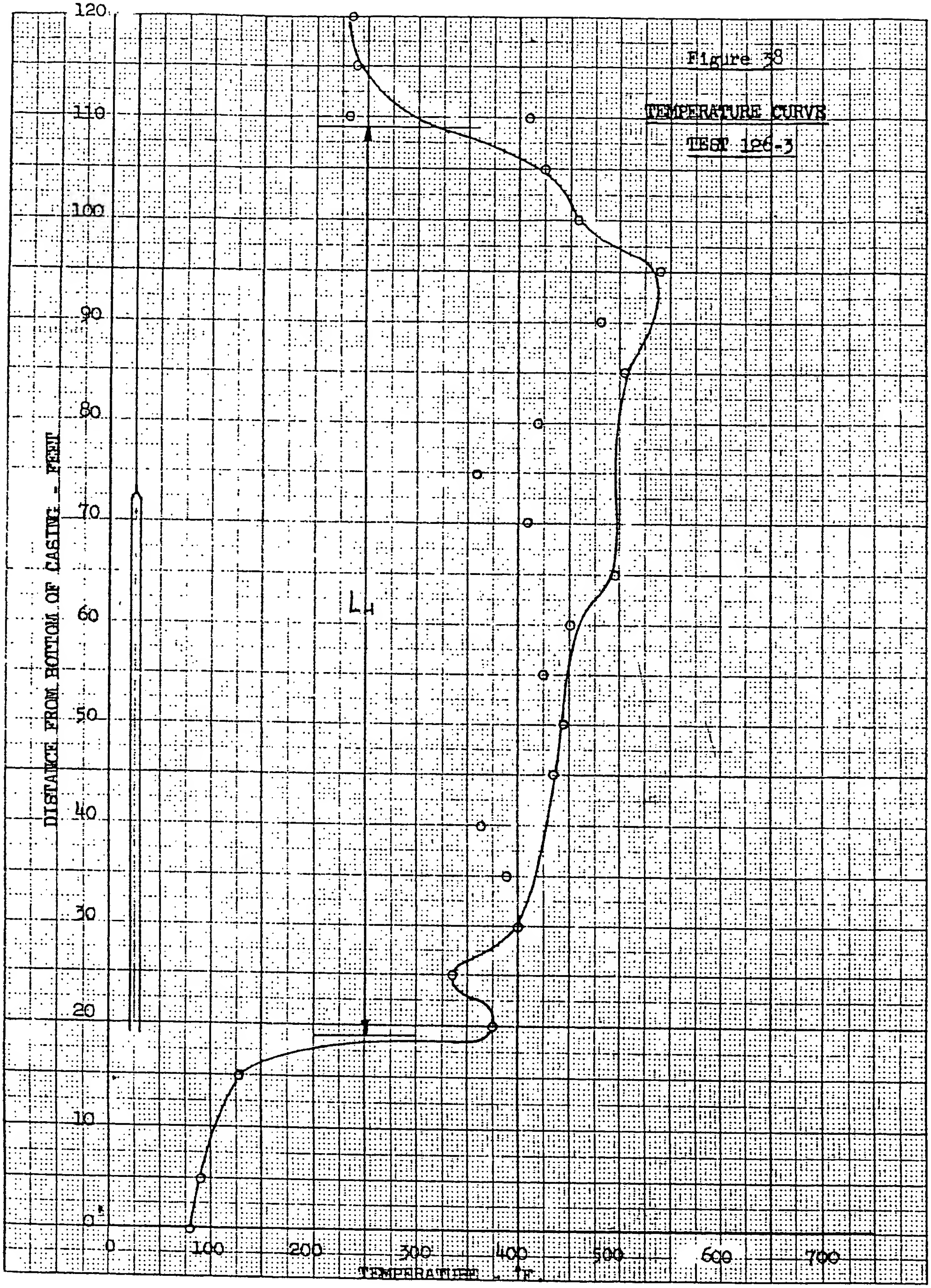


Figure 38
TEMPERATURE CURVE
TEST 126-3
DISTANCE FROM BOTTOM OF CASTING - FEET
TEMPERATURE - °F.
L4
0
100
200
300
400
500
600
700
10
20
30
40
50
60
70
80
90
100
110
120